Geoarchaeology at the Red Tail Site:

Paleoenvironmental Reconstruction of Climate Change during the Holocene

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By Lauren E. Stead

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Abstract

The Red Tail site is one of 19 archaeological sites that lie within central Saskatchewan's Wanuskewin Heritage Park. Since the creation of a long-term research program in 1984, many of these sites have been excavated making this the longest running archaeological project in Canada. This has provided an extensive body of archaeological evidence of human activity dating as early as the Early Precontact Period. Despite the extensive archaeological excavation and research that has occurred, relatively few geomorphic and paleoenvironmental studies have been conducted within the area. Paleoenvironmental data provide important context in building archaeological interpretations of past lifeways.

The Red Tail site was originally excavated in 1988 and 1989 to a depth of approximately 2.7 m. In 2007, the site was revisited in order to conduct subsurface coring to a depth of over 6 m using a Geoprobe coring rig. This method allowed recovery of culturally sterile soils/sediments beyond the depth of the original excavation. This project includes analysis of these cores in order to investigate geomorphic processes active at the site and proxy indicators of paleoenvironment and paleoclimate. Analysis of two of the cores included detailed description of the recovered soils and sediments, as well as stable isotope and phytolith analysis of selected units in one of the cores. This suite of methods provides a robust, multi-proxy interpretation of geomorphic change and paleoenvironmental conditions at the site.

The site was geomorphically active during the Late Pleistocene and Early Holocene, reflective of a dynamic and fluctuating climate following the glacial retreat. As the environment became more stable during the Middle to Late Holocene, periods of landscape stability are reflected in a sequence of buried soils. The paleoenvironmental and paleoclimatic record recovered from these buried soils shows a fairly consistent history of C_3-plant dominated communities, reflective of moist, cool climate conditions. The relatively stable environmental and climatic conditions reflected at the site contribute to the understanding of the Wanuskewin area as an oasis on the prairies.

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Graduate school was certainly not what Nelson Mandela had in mind when he said: "It always seems impossible until it's done". But without doubt, nothing more accurate can be said about writing, editing and defending a thesis. I would never have reached this point in my adventure without the help of many people.

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Chapter 1: Introduction

1.1 Research Background

Climate and environmental data from the archaeological record are an important means of attempting to piece together and understand the lifeways of past cultural groups. Climate and environment would have had considerable impact on the adaptations of groups living across the Northern Plains, encouraging dynamic cultural change as groups responded to shifting opportunities and challenges. In the wake of glacial retreat, cool, moist climates started to become increasingly warm and dry starting sometime after 9 000 B.P. This Middle Holocene period of warm, dry climates, also known as the Altithermal or Hypsithermal, is of particular interest due to the paucity of archaeological material dating to the period. Following this period, climate and environment, generally, returned to cooler, moister conditions during the Late Holocene, presenting past groups with ongoing changes to which they would have had to adapt.

Centered on the Opimihaw Creek tributary of the South Saskatchewan River, Wanuskewin Heritage Park is located approximately 3 km north of the City of Saskatoon (Ramsay 1993; Walker 1983). Archaeological interest in the area began in the 1930s, but it was not until 1982 that a formal survey took place resulting in the identification of 19 sites of archaeological significance (Walker 1983).

One of these 19 sites is the Red Tail site (FbNp-10), which represents a multi-component habitation area located on a break in hillslope adjacent to an ephemeral spring-fed stream (Walker 1983: 49) in the southwestern corner of the park. During 1988 and 1989, excavations of a 44-m^2 area took place, recovering archaeological material ranging in age from recent historic times to over 4 940 B.P. (Ramsay 1993). Of the 15 occupation layers found at the Red Tail site, layers 8 to 15 were identified as belonging to the McKean cultural phase. This cultural phase begins just before 4 000 B.P. on the Northern Plains, near the end of the Hypsithermal. Following the Hypsithermal, climate changed to increasingly moist conditions, which would have prompted the need for McKean cultural groups to adapt to their changing environment. The Red Tail site therefore provides an opportunity to contextualize changing climate and environmental conditions within previously excavated cultural material.

1.2 Site Discovery and Initial Excavation

Although archaeological interest in the area began as early as the 1930s, it was not until 1982 that the site was formally identified. The area that is now known as Wanuskewin Heritage Park was originally homesteaded by Jacob Penner and his family in 1903 and then later owned by the Vitkowski family, who owned the land from 1934 until the early 1980s (Saskatchewan Archives Board 2011; Wanuskewin Heritage Park 2012a). In 1982, Dr. Ernest Walker conducted an archaeological resource assessment of the area, which was purchased by the Meewasin Valley Authority the following year. This original assessment of the Red Tail site included profile excavation of the bank of an ephemeral drainage channel, excavation of three test pits and general surface collection (Walker 1983: 49). This fieldwork identified the presence of two occupation levels and recovered an Avonlea projectile point, along with other flakes, fragments and faunal remains (Walker 1983: 49, 54-57).

In 1984 the land was sold to the City of Saskatoon, and that same year excavation began at two sites within the Opimihaw Valley, the Newo Asiniak and Amisk sites. Excavation has continued at other sites within what was later to become Wanuskewin Heritage Park, making this the longest running active archaeological project in Canada (Wanuskewin Heritage Park 2012b). In 1987, the area was declared a National Heritage Site, and was opened to the public in 1992 (Wanuskewin Heritage Park 2012a).

Excavation at the Red Tail site began in the spring of 1988 with a field school offered by the University of Saskatchewan Department of Anthropology and Archaeology. The first season of excavation included the field school and volunteer excavators during the Saskatchewan Archaeological Society's "Volunteer Week", as well as employed excavators. Nineteen 1-m^2 units were opened during this first season (Ramsay 1993: 8-9). The second season of excavation took place the following year and again included both the field school and employed excavators, but did not include a "Volunteer Week" based on space constraints at the site. Analysis of materials recovered from these excavations was split into two parts. In 1993, Charles Ramsay produced a thesis focusing on the McKean material found in the lower levels at the site, while the analysis of the later material from its upper levels is currently being conducted by Leilani Williams. These excavations and subsequent analyses provide the cultural background of the Red Tail site; combined with these, my environmental and climatic interpretations will contribute to a more robust understanding of the history of the site and surrounding area.

1.3 Research Objectives

The main objective of this thesis is to improve understanding of past human relationships with the unique environment of Wanuskewin Heritage Park, as well as to look at this relationship in the broader context of the Northern Plains. The large number of sites identified in and around the Opimihaw Valley shows the importance of this area to the cultural groups of the past. Adding paleoenvironmental data to the previous archaeological work does not just enhance academic research, it provides an opportunity to also contribute to Wanuskewin Heritage Park's mission of "increasing public awareness, understanding and appreciation of the cultural legacy of the Northern Plains First Nations people" (Wanuskewin Heritage Park 2008) by bringing valuable new knowledge of human-environment interaction to future public and educational programming at the park. This thesis will also begin to fill the academic need for more paleoclimatic and paleoenvironmental information for the Northern Plains as a region, particularly in relation to the archaeological record. In order to achieve these objectives, the following more specific goals are outlined:

1) To determine the geomorphic history of the immediate site area through analysis of soil and sediment recovered in two Geoprobe cores;

2) To determine if stable isotope analysis and phytolith analysis of soils and sediments are feasible and successful methods for paleoenvironmental reconstruction at the Red Tail site and by implication have potential application to other sites in Wanuskewin Heritage Park;

3) To provide paleoenvironmental context for archaeological research in Wanuskewin Heritage Park specifically and the Northern Plains more generally through a combination of laboratory methods, including the description of soil and sediment in the cores, as well as stable carbon isotope analysis and phytolith analysis.

1.4 Organizational Summary

Including this introduction, this thesis is composed of seven chapters. The summary below provides the basic information found in each chapter. Where dates are discussed, they are recorded as uncalibrated radiocarbon dates and are annotated as B.P., unless otherwise indicated as cal B.P. which reflects a calibrated radiocarbon date.

Chapter 2 includes background information on the geology and geomorphology of the research area, beginning with a broad overview of the Northern Plains and then focusing specifically on the Red Tail site location. This chapter also includes a discussion of previous research on Holocene paleoenvironment and paleoclimate on the Northern Plains. Background information on the methods used to complete this study, including field and laboratory methods, are also included in this chapter. Chapter 2 concludes with a summary of the current climate and ecology found at the Red Tail site and within Wanuskewin Heritage Park.

Chapter 3 provides an overview of the current understanding of the cultural history of the Northern Plains. This cultural chronology encompasses the Middle Precontact Period through to the Late Precontact Period with particular attention paid to the McKean occupation of the Red Tail site.

Chapter 4 sets out the field and laboratory methodology used to complete this study, while Chapter 5 presents the results of this analysis. Results include stratigraphic columns based on descriptive logging of the cores, carbon content analysis, stable carbon isotope analysis, phytolith analysis and radiocarbon dates. These results are supplemented with additional information located in the appendices.

Chapter 6 is composed of the discussion and interpretation of the results presented in Chapter 5. This includes a geomorphic history of the Red Tail site, a discussion of the paleoenvironmental and paleoclimate conclusions, and a brief discussion of the correlation between these findings and the previously excavated archaeological material at the site.

Chapter 7 reviews the research objectives and provides a synopsis of the conclusions to those questions. It also identifies areas for future research to complement the findings of the current study.

Chapter 2: Background

2.1 Introduction

The Red Tail site is situated within the boundaries of Wanuskewin Heritage Park, which is located just 3 km north of the city of Saskatoon, Saskatchewan. This is an archaeologically rich area, which offers the opportunity to further our understanding of the history of cultural groups on the Northern Plains since their appearance sometime after the last glacial retreat. The park encompasses an area that includes many archaeological sites situated on the Opimihaw Creek, a tributary of the South Saskatchewan River, as well as some sites on the river itself.

The intent of this chapter is to provide important physical background information about the Northern Plains, and more specifically the immediate area of the Red Tail site. It presents the current state of knowledge on deglaciation, post-glacial landscape evolution, and paleoenvironmental reconstruction of the Northern Plains. These are important factors in understanding the relationship between environment and cultural groups living in the area in the past. The physical environment and climate history of the area would have had significant impact on the adaptations of groups living across the Northern Plains, encouraging dynamic cultural change as groups responded to shifting opportunities and challenges. This chapter also reviews the background on the paleoenvironmental methods used in this study to reconstruct these conditions in the past.

The study area falls within the geographical boundaries of the Northern Plains and as such the physical background information outlined in this chapter will concentrate on this area. The Northern Plains are the northern portion of the Great Plains, a vast expanse of grasslands in the west-central part of North America. The Great Plains cover an area of approximately 1 166 000 km^2 and stretch from as far south as eastern New Mexico and central Texas to as far north as central Alberta and Saskatchewan (Figure 2.1) (Gilbert 1980: 8). The Northern Plains are transected by the Missouri Coteau, a long narrow strip of upland prairie that stretches across the southeast corner of Saskatchewan and the southwest corner of Alberta. The Coteau consists of low hummocky grassland dotted with prairie potholes. The general boundaries of the Northern Plains cover the areas of central/south Alberta, southern Saskatchewan and southwestern Manitoba in Canada and Montana, Wyoming, North and South Dakota and the western edge of Minnesota in the United States (Gilbert 1980: 10-13).

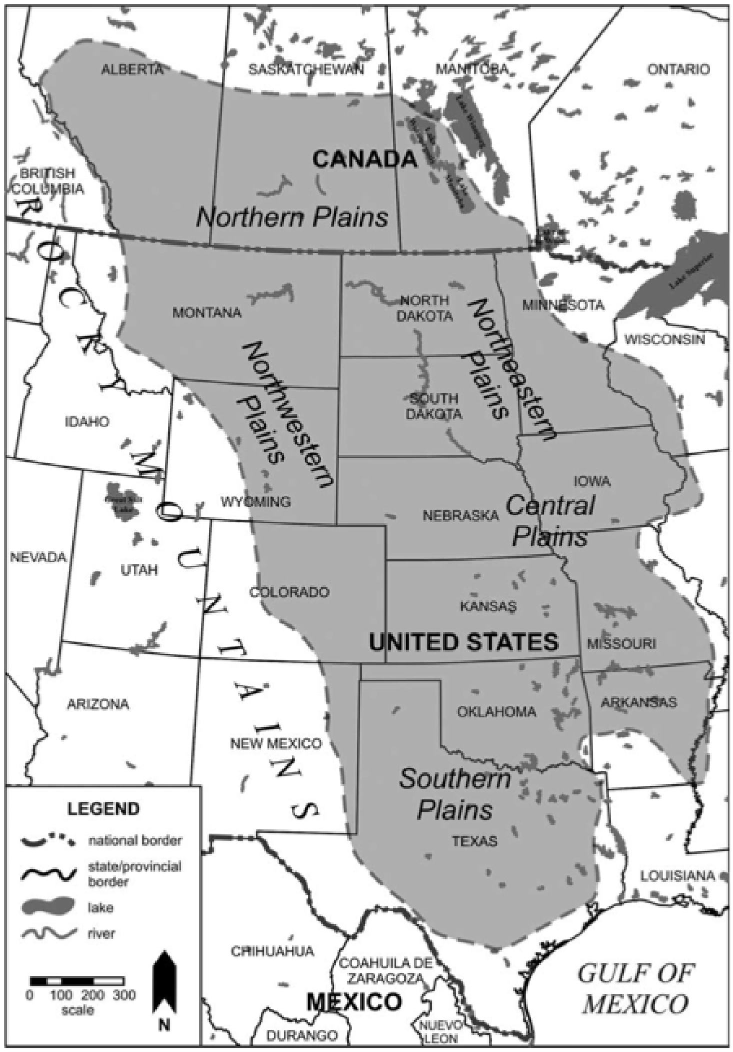


Figure 2.1. Map of Great Plains (Robertson 2011: 182).

2.2 Geologic Background

2.2.1 Lithostratigraphy of Central Saskatchewan

The majority of the landscape in Saskatchewan has been formed by the geologic events of the Quaternary, in particular, the most recent advance and retreat of the Laurentide Ice Sheet during the Wisconsin glacial period (Simpson 1999: 86). The Quaternary is divided into two epochs; the Pleistocene, which involved multiple glacial advances and retreats beginning approximately 2.5 million years ago, followed by the Holocene, which began 11 700 B.P. and continues to the present (Harland et al. 1990). The last glacial retreat began just prior to the beginning of the Holocene at approximately 12 000 years ago. The effects of Pleistocene glacial erosion and deposition can be seen across the province, with a notable difference between the north versus the central and southern areas. In the north of the province, the Precambrian shield was scoured as the Laurentide Ice Sheet expanded south and west across its bedrock surface, collecting material to later deposit elsewhere. Landscapes in southern and central Saskatchewan, including the study area, have been shaped primarily by glacial action and deposition as the ice sheet advanced, melted and retreated.

Prior to glaciation, the Northern Plains, including southern and central Saskatchewan, would have "consisted of broad northeast- and southeast-trending valleys separated by low uplands" (Fenton et al. 1994: 413). It is believed that there were at least five advances and retreats of the Laurentide Ice Sheet (Fenton 1984, Klassen 1989). These advances and retreats, combined with the interglacial periods separating them, have created a complex stratigraphic sequence across the Northern Plains (Fenton et al. 1994). The stratigraphy of these deposits is divided into groups, subdivided into formations and then further still into members.

Table 2.1. Stratigraphic chart of formations and chronostratigraphy of central Saskatchewan. Modified from Christiansen and Sauer 1998: 121; Christiansen 1968: 1170, 1970: 9, 1992: 1775; Whitaker and Christiansen 1972: 356.

			Group	**Formation**
Quaternary	Holocene		Saskatoon Group	Pike Lake Alloformation
	Late Pleistocene	Wisconsin		Holiday Park Alloformation
				Haultain Alloformation
				Battleford Formation
				Floral Formation (Upper)
		Sangamon		Riddell Member
	Early and Middle Pleistocene	Illinoian		Floral Formation (Lower)
		Pre-Illinoian	Sutherland Group	Warman Formation
				Dundurn Formation
				Mennon Formation
			Empress Group	*Sand and gravel*
Tertiary	Pliocene			
Cretaceous	Late Cretaceous		Montana Group	Bearpaw Formation
				Judith River Formation
				Lea Park Formation

Unconsolidated Pleistocene sedimentary deposits in central Saskatchewan are divided formally into the Empress Group, Sutherland Group and Saskatoon Group (Table 2.1). Below these deposits lies marine Cretaceous and non-marine Tertiary bedrock, more than 65 million years old (Whitaker and Christiansen 1972). The Empress Group is made up of Late Tertiary and Early Pleistocene sediments, consisting of interbedded gravel, sand, silt and clay deposits of glacial, fluvial, lacustrine and colluvial origin (Whitaker and Christiansen 1972). In many places these sediments were mostly removed by advancing ice sheets during subsequent glaciations. Any remaining sediments of the Empress Group are found within bedrock valleys and glacially eroded depressions in the bedrock surface (Christiansen 1970: 8, 1979b: 11; Skwara 1988: 27; Whitaker and Christiansen 1972).

Pleistocene sediments of the Sutherland and Saskatoon Groups were laid down during several subsequent glaciations and are comprised of proglacial sediments, till, and postglacial sediments. The Sutherland Group is differentiated from the Saskatoon Group based on carbonate content, texture, stratigraphic position, weathering zones and engineering properties. It ranges from 17 to 71 m thick (Christiansen 1992). Within the Sutherland Group, three separate formations are identified although they are all comprised of glacial till. These are the Mennon, Dundurn and Warman Formations, which all date to the early to mid-Pleistocene (Christiansen 1992).

The Saskatoon Group ranges from 10 to 85 m thick and is divided into the Floral and Battleford Formations, which date to the Early and Late Wisconsinan glacial periods, respectively. Within the Floral Formation, there are tills from at least two glaciations. The formation has been divided up into Upper and Lower portions, but not given further designation because of a lack of distinction between the tills. Between the Upper and Lower tills of the Floral Formation lies the Riddell Member, an approximately 8-m-thick layer of stratified and cross-bedded sand containing fossilized bone, wood and shell. These fossils date to the Sangamon interglacial stage, which makes the Riddell Member the oldest dated stratigraphic unit in the Saskatoon area (Christiansen 1992: 1777; Skwara Woolf 1980, 1981).

The uppermost glacial till unit, the Battleford Formation, ranges in thickness from 0 to 50 m and was laid down during the Late Wisconsinan. The Battleford Formation is described as soft till that is unstained, in contrast to the till of the underlying Floral Formation, which is hard and stained where oxidized (Christiansen 1992).

Surficial stratified deposits dating to the earliest part of the Holocene underlie the present land surface. They are divided into alloformations and then further subdivided into allomembers

(Table 2.1) based on several features, including, for example, carbonate content and texture (Christiansen and Sauer 1998: 126). These deposits are made up of "deglacial lacustrine, outwash and ice-content sediments and post glacial alluvium, colluvium, eolian and landslide deposits" and, as a whole, are up to 100 m thick in some areas (Christiansen 1992: 1776). Some of these deposits accumulated in glacial lakes, which were formed as the ice sheet retreated and impounded meltwater. In other areas, shallow glacial lakes occurred on top of ice sheets, which, when they eventually melted, caused a mixing of the overlying lacustrine sediments with the underlying ablation till. This resulted in the gradational and conformable contact between many of these surficial stratified deposits and the deposits of the underlying Battleford Formation (Christiansen 1992).

2.2.2 Formation of the South Saskatchewan River Valley

Walker describes a series of five phases of Late Pleistocene to Holocene geological events that have shaped the landscape in and around Saskatoon. They are: 1) glacial, 2) glaciolacustrine, 3) glaciofluvial, 4) fluvial, and 5) aeolian (Walker 1983: 17-18). The first phase, glacial, is characterized by the Pleistocene glacial till of the Empress, Sutherland and Saskatoon Groups. The events of the Late Wisconsinan glaciation are very controversial and there are no definitive conclusions on the location or age of the Laurentide Ice Sheet limit (Klassen 1989: 157). Despite this controversy, there is general agreement among scholars on the pattern of deglaciation from southwest to northeast across the continent (Klassen 1989: 157).

The beginning of Walker's glaciolacustrine phase is marked by the creation of glacial Lake Saskatchewan at the end of the Pleistocene. The Late Wisconsinan deglaciation of the southern and central Saskatchewan area began around 12 000 years ago (Christiansen 1979a: 932). The land surface exposed by the retreat of the Laurentide Ice Sheet sloped northeast due to isostatic depression by the ice sheet, an integral component in the development of the post-glacial drainage networks (Kehew and Teller 1994: 864). As the Laurentide Ice Sheet retreated in a northeast direction across the province, glaciolacustrine deposits accumulated in glacial lakes formed where meltwater drainage was obstructed by the depressed topography and glacial ice dams. Elsewhere, meltwater flowing through pre-existing Tertiary river valleys began to carve out the landscape. Glacial Lake Saskatchewan was one of several glacial lakes located across southern and central Saskatchewan (Christiansen 1979b). As the glacier retreated and re-advanced in different areas, glacial Lake Saskatchewan water levels rose and fell. Areas such as the Strawberry Hills, located northeast of Saskatoon, were not inundated with meltwater and remained as islands of Pleistocene glacial till in the glacial lake (Skwara 1988: 34). The North and South Saskatchewan Rivers, along with other meltwater spillways, emptied into glacial Lake Saskatchewan, forming deltas (Christiansen 1979a). The Camp Dundurn Delta, located south of Saskatoon, was created at the entry of the South Saskatchewan River into glacial Lake Saskatchewan (Christiansen and Sauer 1998: 129).

Meltwater trapped in glacial lake basins was eventually released rapidly as natural dams were breached. The draining of these glacial lakes was often relatively sudden, releasing huge amounts of water and inundating spillways, often modifying existing drainages or creating new waterways (Kehew and Teller 1994). Two examples of these sudden outpourings of water include two braid channels, now abandoned, known as the Hudson Bay Channel and the Grass Lake Channel, both located northeast of present day Saskatoon (Christiansen and Sauer 1998: 130). This period of high meltwater discharges marks Walker's glaciofluvial phase.

According to Skwara Woolf (1981: 34), fluvial sand and gravels from preceding interglacial times, such as those that constitute the Riddell Member and the Floral Formation, support the existence of an ancestral South Saskatchewan River that was present prior to the last glacial period. Several Northern Plains drainage systems that predated the last glaciation were rerouted temporarily during its retreat, eventually becoming re-established and more deeply incised by the glaciofluvial activity following the ablation of the glacier. The South Saskatchewan River, as it stands today, was established as the volume of glacial meltwater decreased and the drainage channels became increasingly stable. As the ice retreated northward past Elbow, Saskatchewan, the modern courses of the South Saskatchewan River were established (Kehew and Teller 1994: 864). Figure 2.2 illustrates the location of the Red Tail site during the stages of the formation of the South Saskatchewan River Valley following the drainage of Glacial Lake Saskatchewan. This was concurrent with Walker's fluvial phase.

Climatic conditions dating from approximately 8 000 to 5 000 years B.P. in North America were warm and dry, which resulted in a significant decrease in water flow and postulated down cutting of the Opimihaw Valley as it adjusted to changes in the South Saskatchewan River (Walker 1983: 18).

Following the ablation of the ice sheet, three terraces were formed along the South Saskatchewan River Valley in the Saskatoon area by changing discharge levels due to fluctuations in climates in the region. The initial period of valley degradation occurred prior to 7 000 years B.P. Climatic change resulted in the formation of the Saskatoon Terrace and in the later stages a veneer of overbank deposits was laid down on top of the erosional surface (Walker 1992: 29). Neoglacial advances in the Rocky Mountains (see section 2.4.2 Late Holocene Climate Change), where the headwaters of the tributaries of the Saskatchewan River are located, appear to have been associated with further down cutting and incision of the valley (Walker 1992: 29). These occurred around 6020 years B.P. and 4 700 years B.P. Walker suggests that the lower terraces of the South Saskatchewan River, such as the Poplar Crescent Terrace, formed as a result of reduced discharges associated with the Neoglacial stade (Walker 1992: 29). The Neoglacial stade is a climatic episode within a period of glaciation during which a secondary advance of the ice sheet took place.

Walker's final phase, the aeolian phase, involved the creation of sand dunes, but does not directly relate to the study area (Walker 1983: 17-18).

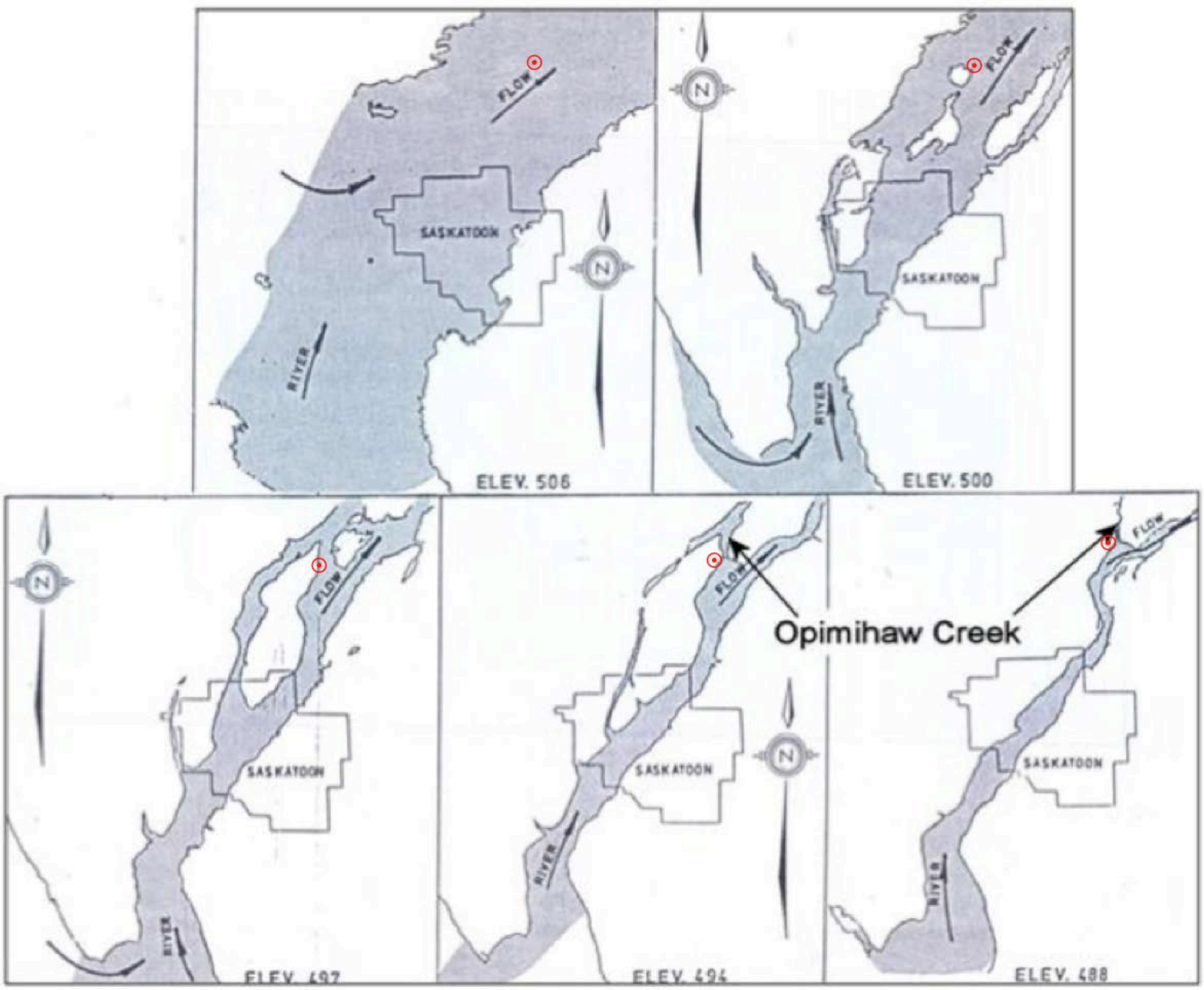


Figure 2.2. Approximate location of the Red Tail site during the stages of the formation of the South Saskatchewan River Valley in Saskatoon. (After Clifton Associates Ltd. 1985).

2.3 Geomorphology of the Red Tail Site

Wanuskewin Heritage Park is centered on the Opimihaw Creek tributary to the South Saskatchewan River. This tributary is most likely a braid channel of the South Saskatchewan River that was abandoned as the volume of glacial meltwater decreased starting around 8 000 to 7 000 years B.P.; it now holds an underfit stream (Figure 2.3). While the majority of archaeological sites within the Park are found along the Opimihaw Creek, the Red Tail site is located in the southwest corner of the Park along the South Saskatchewan River Valley. Both valleys cut through the Floral and Battleford formations of the Saskatoon Group as defined above (Christiansen and Sauer 1998). Deposits along the valleys include sand and gravel deposited by flowing water, underlain by clays and silts deposited within post-glacial lakes (PFSRB 2009: 48). Since initial incision, alluvial activity and colluvial processes have subsequently reshaped both the South Saskatchewan River Valley and the Opimihaw Creek Valley.

The Red Tail site is far enough away from the Opimihaw Creek that overbank deposits formed by periodic flooding of the creek or erosion due to meandering of the creek would not affect the site. Stratigraphy at the site is complex, with indications of both fluvial and colluvial depositional environments (Burt 1997: 147). Deposition would most likely occur during flooding of the South Saskatchewan River or due to gravity-related sediment inputs upslope of the depression. The Red Tail site is located on the outside of a meander bend of the South Saskatchewan River, but not in the area of active erosion at the present time. Its position on the outside of a meander bend makes it susceptible to particular processes to be discussed below. The site sits in a slight break in the valley wall near an ephemeral stream that drains into the South Saskatchewan River.

2.3.1 Hillslope Processes

There are a number of hillslope processes that may have occurred in the past, and some that continue to be active within Wanuskewin Heritage Park. Presented below are some of the possible hillslope processes that may have contributed to deposition at the Red Tail site during the Holocene. Any evidence for these processes that appears within the cores will be discussed in subsequent chapters.

The Red Tail site is located within a break in the slope on the outside of a meander bend of the South Saskatchewan River Valley. This break may have resulted due to a hillslope process known as slumping. Slumping (Figure 2.4), a mass movement process, occurs when a coherent mass of

Figure 2.3. Location of the Red Tail site, Wanuskewin Heritage Park (after Google Earth 2009).

material moves down slope in one rapid movement (Summerfield 1991:172-173). A rotational slump occurs when a slump block moves along a concave-upward slope surface causing the wall of the valley to become less steep and therefore more stable. This type of slumping is particularly common in areas where slope sediments consist of thick, homogeneous materials, such as the glaciolacustrine clays that occur along the South Saskatchewan River Valley (Summerfield: 1991: 172). There are a number of sites within the Opimihaw Creek Valley where evidence exists of slumping caused by undercutting by the creek (Burt 1997; Rutherford 2004). Increased moisture in the sediments, especially relatively sudden inputs such as overbank flow or spring runoff, is a critical factor in slope instability resulting in slumping (Beaty 1972). In the section of the South Saskatchewan River Valley north of the City of Saskatoon where the walls of the valley are quite steep, slumping is a common occurrence. The Red Tail site's location on the outside of a meander bend also makes the area particularly vulnerable to undercutting and slumping (PFSRB 2009: 51). The outside wall of a river valley can become over-steepened due to erosional undercutting resulting in failure of the slope.

However, downstream migration of the meander bend means that today the Red Tail site is no longer in the area of active erosion and is therefore far less susceptible to undercutting and potential slumping.

Continued hillslope activity, including processes such as debris flow, began in the South Saskatchewan River Valley by at least 3864 ± 55 B.P. and continues to be a concern particularly on the east side of the riverbank (Clifton Associates Ltd. 1984: 40; Rutherford 2004: 91). Both the Opimihaw Creek and South Saskatchewan River valleys show a period of frequent slope instability between 4,500 and 3,500 years B.P. based on a stratigraphy of numerous weakly developed buried soils separated by hillslope sediment (Rutherford 2004: 93). Slope instability would have increased with the developing trend towards cooler, moister conditions that regional paleoenvironmental reconstructions indicate followed the Hypsithermal.

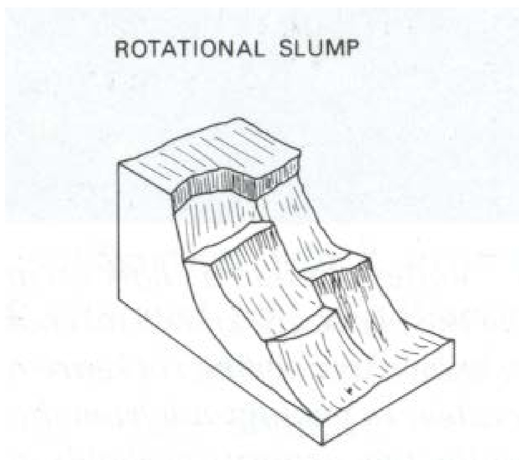


Figure 2.4. Rotational slump, a type of mass movement (Summerfield 1991: 172).

Rutherford (2004) studied hillslope sediments at four archaeological sites within Wanuskewin Heritage Park, two located on the Opimihaw Creek Valley and two on the South Saskatchewan River Valley. Rutherford identifies several hillslope processes that are dominant in the development of slopes in Wanuskewin Heritage Park (Rutherford 2004: 19-23). Based on her previous work, she identifies the predominant process as debris flow, which is defined as a fast moving mixture of poorly sorted sediment and water moving downslope under the influence of gravity (Summerfield 1991: 170). Common triggers of debris flow include intense rainstorms or rapid snowmelt, both currently prevalent at different times of the year through the valley. The highest rates of Holocene slope erosion are attributed to decreased vegetation cover combined with high intensity thunderstorms (Bettis 1992). Thunderstorms are especially prevalent in southern

Saskatchewan during the dry summer months. These storms are often characterized by a significant amount of precipitation falling in a short period of time (PARC 2013). This influx of precipitation has consequential impact on the sediments along the valley and can result in debris flows, which would result in the deposition of coarse, poorly sorted material. This would certainly have been a hillslope process that contributed to deposition at the Red Tail site and continues to be an active process today.

Vegetation has a considerable impact on the stability of a landscape. Lush plant communities contribute to increased slope stabilization and erosion control through ground cover and by roots providing physical reinforcement of the sediments. During periods of climate conditions not conducive to plant growth, slopes would be increasingly unstable. Both desiccation of sediments due to dry climate conditions and increased soil moisture can also result in slope instability, as the former removes adhesive forces by low quantities of water in sediment pore spaces and the latter pushes sediment apart by overfilling these pore spaces.. Factors of slope stability such as moisture content and vegetation cover could have been variable in response to climate change throughout the Holocene.

2.3.2 Alluvial Processes

Tributaries in southern Alberta, Saskatchewan, and northwestern Montana feed the South Saskatchewan River. The main feeders are the Red Deer, Bow and Oldman Rivers, which all originate in the Rocky Mountains and foothills (Lamers 1988: 1). In 1959, the construction of Gardiner Dam, one of the largest earthfill dams in the world, commenced. The project was completed in 1967 and now restricts a considerable amount of the South Saskatchewan River's flow and has affected the frequency of large flood events (Lamers 1988: 3). Prior to the construction of the dam, mean annual peak discharge of the South Saskatchewan River was 1536 m^3 sec^{-1}, but since construction, peak discharge has dropped to 595 m^3 sec^{-1} (Sambrook Smith et al. 2006: 415). Figure 2.5 illustrates the effect of the construction of the Gardiner Dam on flow rates. Prior to dam construction, the seasonal flow peaked in July once snowmelt from the mountains had made its way to the prairies. Construction of the dam resulted in the ability to regulate seasonal flow, the outcome of which is a relatively consistent year round flow (PFSRB 2009: 117).

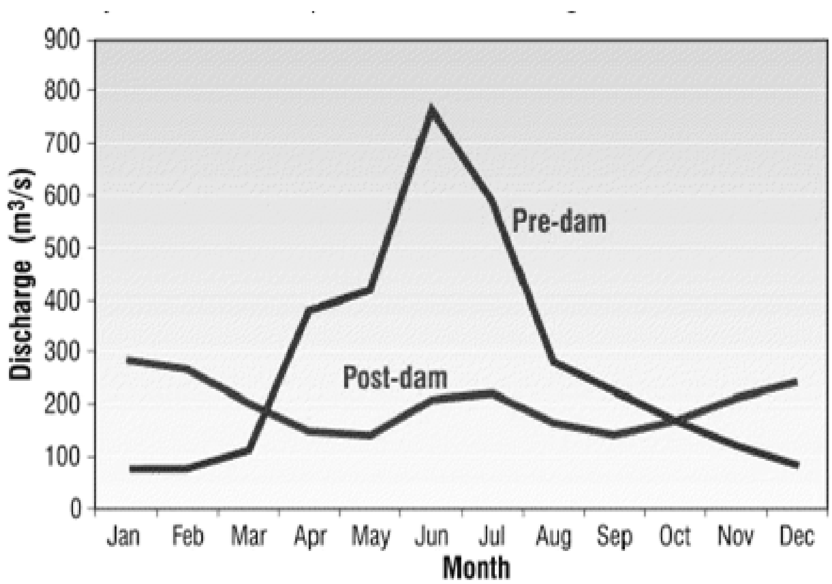


Figure 2.5. Change in peak water discharge in the South Saskatchewan River Basin following the construction of the Gardiner Dam (PFSRB 2009: 117).

Even with this drop in peak discharge, the South Saskatchewan River still occasionally floods downstream from the Gardiner Dam. The greater discharge prior to dam construction suggests flooding and overbank deposits, as well as opportunities for fluvial erosion, would have been more frequent and of greater magnitude. Historical records show flooding of the South Saskatchewan River to an elevation of 15 m above present levels (A.Aitken, personal communication 2013). GPS analysis during the spring of 2013 indicated that the site is well within this 15 m flood zone, making it susceptible to past flood events and creating opportunities for both overbank deposition and fluvial erosion. Figure 2.6 indicates the elevations of various points taken in the Red Tail site area. The Red Tail site sits 9.7 to 11.3 m above the present water level of the South Saskatchewan River and 6.0 to 7.5 m above a terrace that would have once been the river's bank. Only a month following the recording of these data, catastrophic flood events upstream from the South Saskatchewan River resulted in record water levels of approximately 2 m above normal, despite the various water control devices in place throughout the watershed.

Figure 2.6. Elevations of the Red Tail site taken using a Trimble GeoXH, with accuracy to less than 15 cm.

As mentioned, there is also an ephemeral stream located in close proximity to the Red Tail site. Ephemeral streams are dry for most of the year, but flow during and after periods of peak moisture, such as spring snowmelt or the torrential downpour of a summer storm. During these events, this ephemeral stream could have contributed to the deposition and erosion occurring at the site.

2.4 Paleoclimatic and Paleoenvironmental Background

2.4.1 Early and Middle Holocene Climate Change

Climate change throughout the Holocene has been interpreted and defined across the globe. Ernst Antevs developed a classification scheme specific to the North American Great Basin in 1955. Through several lines of evidence Antevs defined three periods: Anathermal (9 000-7 000 B.P.), Altithermal (7 000-4 500 B.P.) and Medithermal (4 500 B.P. - present) (Antevs 1955). Antev's Anathermal, the initial period after the retreat of the glaciers, is described as a cool, wet period, in contrast to the Altithermal, which was warmer and more arid. The beginning of the Medithermal coincides with the onset of current climate conditions. This initial framework for paleoclimatic reconstruction has led the way for further research in the area, with further refinement of timing of the transitions between periods and idiosyncrasies of regional climate change. A basic framework of Early Holocene cool, wet climate and environment following the retreat of the glaciers, followed by a Middle Holocene period of warmer, drier conditions and a return to cooler, moister conditions in the Late Holocene will be used to outline the climate history discussed in this thesis. An example of this now-common and useful tri-partite approach to North American Holocene climate change can be seen in Figure 2.8.

The Altithermal is particularly interesting to archaeologists on the Northern Plains because it has been a period of substantial controversy. Not only has the terminology used in describing this period of climatic warming been contested, but also the extent to which these changed climatic conditions affected cultural groups in the area has been debated. As research on climatic conditions and change during the Holocene on the Northern Plains has developed, alternative terms to the Altithermal have been presented. At present, the preferred alternative is the Hypsithermal, which was first proposed by Deevey and Flint (1957: 183) because they felt that terms such as postglacial climatic optimum, thermal maximum, and megathermal were ambiguous in describing the period. The term Hypsithermal is currently favoured because its long time frame (9 000-2 500 B.P.; Deevey and Flint 1957: 182) encompasses the full duration of what is now recognized as a time transgressive event with several maxima and intervening cooler phases (Anderson et al. 1989; Barnosky et al. 1987; Vance et al. 1995: 94).

The warmer and drier conditions of the Hypsithermal started and ended first in the northern and western parts of the Great Plains and moved towards the east. The onset occurred sometime between 9 000 and 7 000 B.P. across the Northern Plains and ended between 6 000 and 4 000 B.P., depending what part of the region and what kind of paleoenvironmental records are considered (Anderson et al. 1989: 528; Barnosky 1987: 71-72; Vance et al 1995: 93-94). Proxy evidence from across the Northern Plains taken from lake pollen records, diatoms and ostracods show that there was greater variation in climate within the Hypsithermal than previously thought (Vance et al. 1992: 881; Yansa 2007: 130). Rather than a period of several thousand years of persistent drought and general warming, there were shorter periods of less extreme temperatures and increased moisture interspersed between several droughts.

Evidence from available proxy records points to shifting zones of vegetation in response to the changing climate, a process which altered the presently accepted geographic boundaries of the

Northern Plains based on migration of its characteristic prairie vegetation. Gryba (1980: 41) suggests, based on pollen records, that the "extension of the prairie zone along the northern border of the Plains was probably in the order of 50 to 70 miles". This extension of boundaries places areas that are currently considered peripheral to the Northern Plains proper much more securely within them. Wanuskewin, for example, is an area that currently lies on the boundary between the grasslands of the Northern Plains and the adjacent aspen parkland region, but during the Hypsithermal it would have arguably been located within the Northern Plains.

Response of human populations to the Hypsithermal has been a controversial topic among archaeologists over the past fifty years. One hypothesis, first introduced by William Mulloy, describes a "climatically induced cultural hiatus", during which it was believed that human populations once occupying the Northern Plains deserted the area during periods of severe drought (Mulloy 1958). This became known as the "Hiatus" model and at the time was supported by an apparent absence of archaeological material found dating to this period. However, as archaeological evidence for human occupation of the Northern Plains during this period accumulated, others suggested that while populations on the Plains were reduced during periods of particularly arid conditions, the area remained inhabited. Rather than abandonment, mobile groups reliant on a bison-focused subsistence strategy would have utilized areas surrounding permanent water sources. This "Refugia" model suggests a drop in population across the Northern Plains leading to a concentration of sites in the more hospitable periphery and valleys of the Northern Plains (Buchner 1980: 205; Hurt 1966: 111; Husted 2002; Kornfeld et al. 2010; Sheehan 1995: 268). Hurt (1966) concludes that while human and game populations during this time period would have been small, human populations would have remained, developing alternate subsistence strategies. Reeves (1973) argues that there is a paucity of data dating to the period due to geomorphic processes. He points out that many sites only contain evidence of a human population dating within the past 5 000 years, starting with the McKean Complex. He argues that geomorphic processes affected site preservation of evidence prior to McKean occupation either through erosion or deep burial of sites. The ambiguity in identifying projectile points dating from these earlier periods may have also resulted in an underrepresentation of sites (Reeves 1973). Resolving the issue of human response to climate change necessitates a better understanding of the regional complexities and variations of the paleoenvironmental and paleoclimatic record, combined with archaeological exploration across the Northern Plains.

Most of the proxy data available for the Northern Plains comes from the pollen records of lakebeds. This method of acquiring data is not always particularly useful for studies of Early to Middle Holocene climate on the Northern Plains because of the lack of lakebeds that retained perennial water during the increased aridity of the Hypsithermal (Yansa 2007: 109-110). Harris Lake, located on the northern edge of the Cypress Hills of southwestern Saskatchewan, is particularly significant to paleoenvironmental reconstruction on the Northern Plains because it retained some water, while other lakes outside of the Cypress Hills completely dried up during the periods of warmer, more arid climates (Beaudoin 1993: 93; Porter et al. 1999: 36). As a result, Harris Lake provides one of the few pollen records that stretches back to the Early Holocene, with a basal date of 9120 ± 250 B.P. (Sauchyn and Sauchyn 1991: 1, 13). In addition to pollen, organic matter, sedimentation rates and ostracods were also analyzed in the cores. A variety of these proxies were used to infer changing water levels and chemistry, temperature, precipitation and vegetation (Porter et al. 1999; Sauchyn 1990).

The palynological results from the Harris Lake core reflect a peak in the warm, arid conditions around 7700 to 5100 B.P., followed by a shift to a cooler, moister climate starting around 4500 years B.P. (Sauchyn and Sauchyn 1991: 17-19). The results from ostracod assemblage analysis, however, show a later peak in the warm, arid conditions occurring around 6400 to 4500 year B.P., followed by a shift to cooler, moister climates beginning at the same date of 4500 years B.P. (Porter et al. 1999: 39-41). Porter et al. suggest that these discrepancies could be attributed to the mixed ecological zones at the site. While the watershed is located in predominantly coniferous forest, it is also at the edge of mixed grass prairie, which would have affected the pollen record at the site (Porter et al. 1999: 42).

Pollen data at Ceylon Lake, located in southern Saskatchewan, show a warm, arid climate prior to a period of relatively cool conditions beginning around 6 000 to 7 000 years ago. Conditions then returned to warmer temperatures, but were less arid than initially (Last 1990: 236). These pollen data are complemented by Last's analysis of the sedimentary record of this small, ephemeral saline lake. The lake originated as a large, deep fresh water lake around 15 000 years ago, but then underwent significant fluctuations in water levels, water chemistry and salinity, and sedimentary-depositional setting (Last 1990: 235). Also, around 6 000 years ago, the lake became increasingly shallow and saline, with several periods of complete desiccation. Approximately 5 000 years ago, the lake became hypersaline and evaporative, conditions which have remained generally consistent ever since (Last 1990: 236).

Chappice Lake is another example of a locality in the Northern Plains that has yielded considerable proxy data during the Hypsithermal. The lake is currently a small, shallow, hypersaline lake located near the limit of the northern mixed grass prairie in southeastern Alberta (Vance et al. 1993: 104). Two cores were recovered from the lakebed and analyzed to produce a record reaching back to 7 300 years B.P. This record generally coincides well with other assessments of general trends of climate change during the Holocene (Vance et al. 1992: 880, 1993: 103). From the base of the core (7 300 years B.P.) to the layers that correspond with about 6 000 B.P., there is evidence for periods where the lake was completely desiccated, interspersed with periods when the climate was wetter and the lake level was high. This indicates a much more variable climate during this period than other paleoenvironmental reconstructions might suggest (Vance et al. 1993: 117).

Oro Lake, located approximately 80 km southwest of Regina, Saskatchewan, is another of the very few lakes on the Northern Plains that has a complete, uninterrupted sequence of sediment accumulation spanning the last 10 000 years. Several cores were taken from three localities in the Oro Lake basin, the longest of which measured 8.13 m and begins about 9 700 years B.P. (Last and Vance 2002). Based on thick accumulations of sediments void of exposure horizons, unconformities and pedogenic zones, the lithostratigraphy of the recovered cores shows that the lake did not experience any prolonged periods of desiccation during the Holocene (Last and Vance 2002). The lake began as a freshwater lake, but as with other lakes in the region, at 9 300 years B.P. it abruptly changed to a saline lake. Peak salinity levels, and therefore inferred peak climate aridity, occurred at approximately 8 300 years B.P. The post-Hypsithermal paleoclimatic record based on lithostratigraphy at Oro Lake is somewhat ambiguous and could be interpreted in a number of different ways. Stable carbon and oxygen records, however, demonstrate decreased aridity following peak salinity, which is congruous with the paleoenvironmental records of the region (Last and Vance 2002).

Yansa (1998) uses a collection of well-preserved plant macrofossils found at the Andrews site, a prairie pothole feature common in the hummocky moraine, to determine vegetation shifts and climate history. The record found at the Andrews site indicates that the hydrology and climate of the area were significantly different in the past than the modern conditions. Evidence points to Hypsithermal climate change occurring at the site between 8800 and 7700 years ago. This window of onset dates later than other areas where evidence of Hypsithermal onset begins between 10 000 and 8 000 years ago. This discrepancy between dates speaks to the time-transgressive nature of the Hypsithermal (Yansa 1998: 438).

Yansa (2007) reports on research conducted on two lakes in North Dakota, Coldwater Lake and the paleolake known as the Wendel site, and also provides a summation of vegetation and lake level changes at several other lakes in the region. Vegetation and lake level changes are inferred from geochemistry, stable isotopes of ostracod calcite and plant macrofossils and/or diatoms (Yansa 2007: 122). At Coldwater Lake, peak salinity begins just before 6 000 years ago, while the paleolake at the Wendel site had dried up by around 8 000 years ago, as indicated by the presence of a buried soil. Yansa's conclusions of a period of highest aridity around 6 000 years B.P. correlate with other paleoenvironmental reconstructions in the area, but she also notes "that further paleoenvironmental and archaeological research needs to be conducted to identify the nature of human responses to the ever-changing climate of the Northern Plains" (Yansa 2007: 138). Figure 2.8 offers a diagrammatical summary of the paleoenvironmental evidence from many of the studies discussed here. It shows the correlation between the studies and the general dry conditions prior to a shift towards cooler, moister conditions beginning around 6 000 years B.P. It also illustrates the onset of modern climate and environmental conditions at the various localities (Figure 2.7).

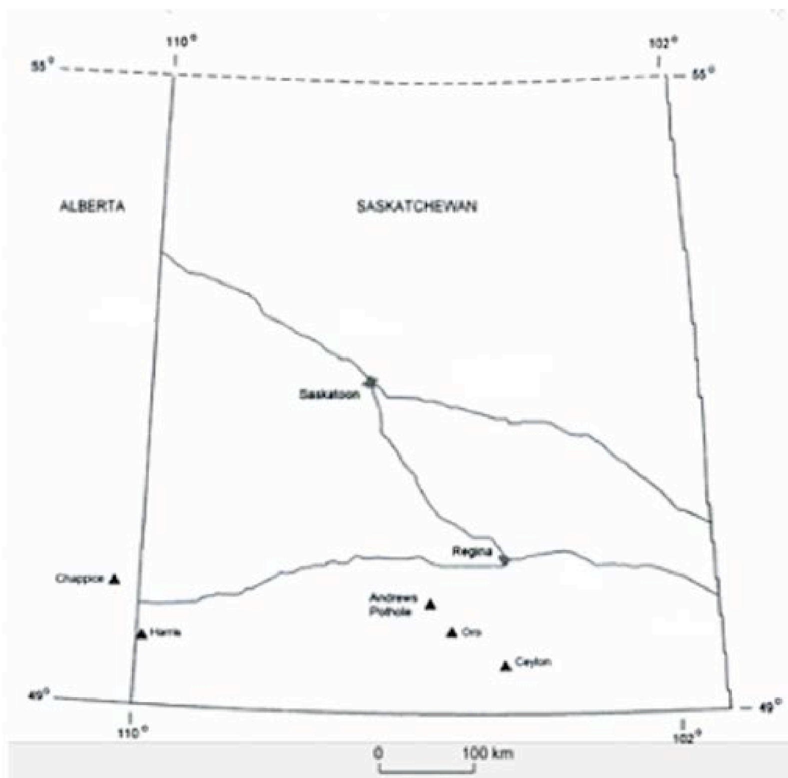


Figure 2.7. Locations of discussed paleolimnological records (Sauchyn and Vélez 2007: 58).

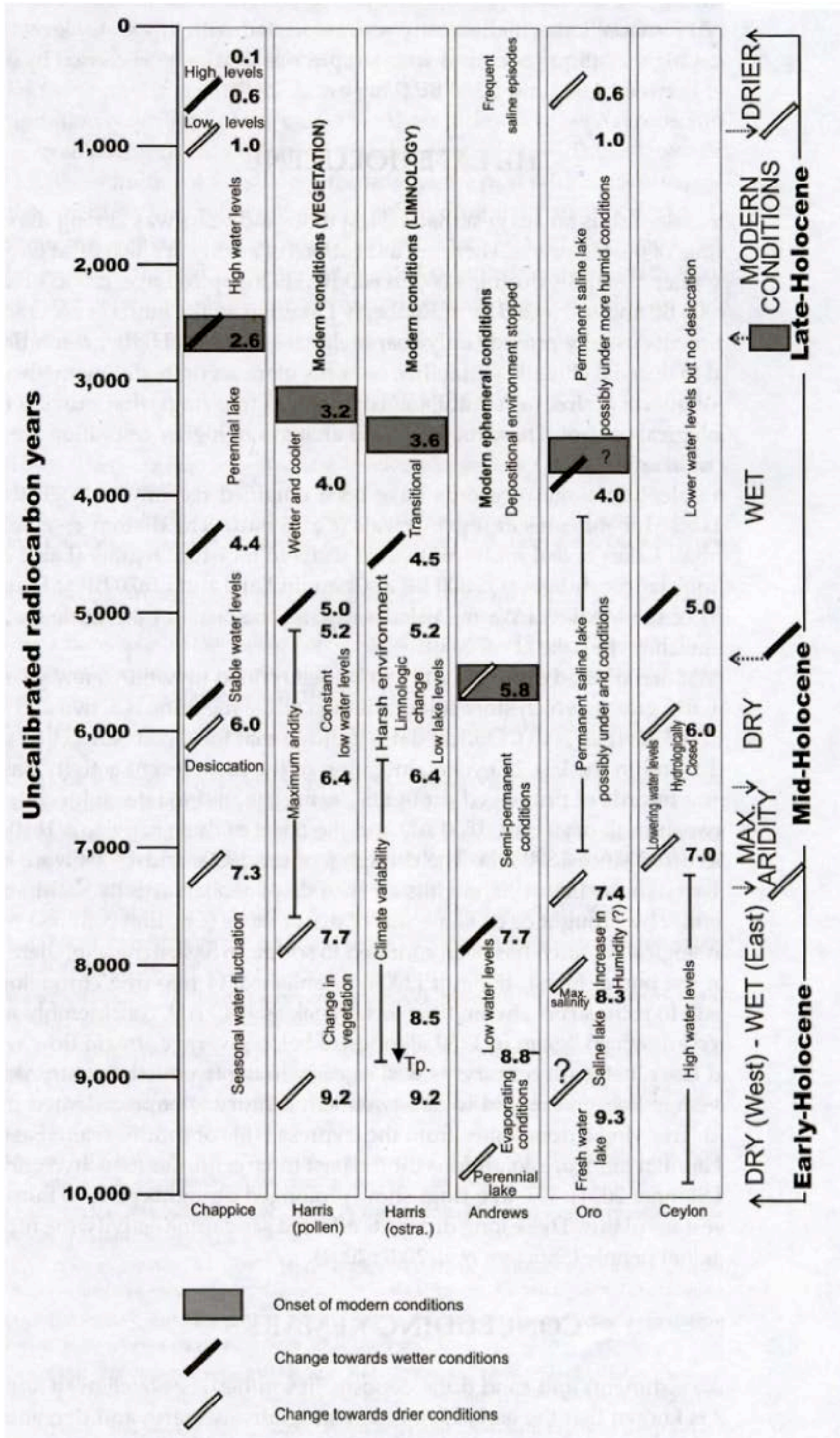


Figure 2.8. Diagrammatic summary of discussed paleolimnological records illustrating changes towards wetter or drier conditions and the onset of modern conditions (after Sauchyn and Vélez 2007: 59).

2.4.2 Late Holocene Climate Change

Following the Hypsithermal, the climate became cooler and wetter than at present, with a shift back towards modern climate conditions, which were still more moderate than those of the Hypsithermal, beginning by at least 3 000 years B.P. (MacDonald and Ritchie 1986; Sauchyn and Sauchyn 1991; Vance et al. 1983, 1992). Climate variability still occurred during the last 3 000 years, with periods of cooler or warmer climates as outlined below. This generalized post-Hypsithermal shift to more humid conditions is evidenced by various indicators including rising lake levels, changes in ostracod assemblages, decreasing lake salinity and increases in tree and shrub pollen (Sauchyn and Velez 2007: 57-60). At the aforementioned Chappice Lake, an interval of higher lake levels occurs at approximately 6 000 to 4 000 years B.P., while at Harris Lake, pollen changes indicate a more humid interval around 5 000 to 3 200 years B.P. (Sauchyn and Sauchyn 1991; Vance et al. 1992).

These cooler, wetter conditions contributed to a Neoglacial advance of glaciers worldwide starting between 5 000 to 2 000 years ago (Lamoureux and Cockburn 2005: 619). Porter and Denton (1967: 205) define Neoglaciation as a "climatic episode characterized by rebirth/and or growth of glaciers following maximum shrinkage during the Hypsithermal interval". During this period there were numerous glacial advances and retreats with continental Europe being most strongly impacted. It was not, as previously believed, a globally synchronous cold period, and considerable variation occurred between regions, unlike the worldwide expansion of the glaciers during the Pleistocene (Mann 2002: 505-507). In the Northern Plains, the cooler, moister climate resulted in advancement of the alpine glaciers in the Rocky Mountains, resulting in a modest drop in average temperatures (Mann 2002: 504).

The climate of the past millennium across the Northern Plains can be divided into two main phases. From approximately 1 060 to 700 years B.P., increased drought severity reflected in low lake levels and higher salinity corresponds with the period known as the Medieval Warm Period (M.W.P.) (Peck 2011: 323). The later half of the millennium, from about 500 to 100 years B.P., saw generally cooler, moister climates than the preceding period, with renewed glacial advances in the Rocky Mountains (Anderson et al. 2007: 181-183; Grove 2003; Lemmen and Vance 1998: 49; Sauchyn and Beaudoin 1998: 343). This period is known as the Little Ice Age (L.I.A.) and was first identified based on historic records in Europe. Critics of the L.I.A. argue that there is "no evidence for a worldwide synchronous and prolonged cold interval to which we can ascribe the term 'Little Ice Age'" (Bradley and Jones 1995: 659-660).

While there is no evidence for worldwide synchronicity of these more recent climatic events, there is evidence for considerable climate fluctuations during this period. The coldest portion of the period known as the L.I.A. occurred in Europe during the seventeenth century, or 350 – 250 years B.P., while in North America, the nineteenth century marked the coldest temperatures (Mann 2002: 507). Rather than a period of consistently cooler temperatures and increased precipitation, the period known as the L.I.A., especially in the area of the Northern Plains, may be best characterized as a period of considerable climate variation, season-to-season and year-to-year (Mann 2002: 507).

The climate of the Northern Plains during the last century has continued this pattern of variability, though average temperatures and precipitation have increased overall (Vincent et al. 2004: 5). The rate of increase of temperatures has accelerated over the last half of the twentieth century and into the twenty-first century (Vincent et al. 2004: 6). This increase has lead to concerns regarding global warming as the "forecast rate of warming is unprecedented in recent geological time" (Vincent et al. 2004: 7).

2.4.3 Proxy Indicator Background

The methods of investigation used in this project were chosen because they complement one another to give a robust, multi-proxy interpretation of the paleoenvironmental conditions at the site. Background information on each of the methods used in this investigation is outlined below. This suite of paleoenvironmental indicators is especially useful for analyzing terrestrial deposits from the Northern Plains region, where other indicators, such as pollen, may be poorly preserved. An important objective of this research was to identify possible buried soils in the depositional sequence at the site. Buried soils were once stable, vegetated land surfaces that have since been buried by sediment, ending any active soil development processes (Waters 1992: 57). These buried soils are particularly important because they supported various vegetation communities and may have also supported human occupation. Samples from these stable surfaces can yield distinctive isotope signatures and phytolith assemblages reflecting the conditions under which the soils formed and vegetation grew. Combining these paleoenvironmental data with evidence of contemporaneous archaeological occupation can contextualize the archaeological data and enhance insights into the lifeways of site residents.

2.4.3.1 Particle Size Analysis Background

Particle size analysis is used to determine the size of the particles within the sediment and soil layers. Distinctions are generally made between boulder-, cobble- and gravel-sized particles, which measure greater than 2 mm in diameter, and on a finer scale, sand, silt and clay, which are less than 2 mm in diameter (Gerrard 2000: 22). Based on the relative proportions of the various particle sizes in sediment, the textural class of the sediment can be identified. Particle size distributions can also help to infer high versus low energy depositional environments and are therefore an important component in understanding the formation of a site (Rapp and Hill 2006: 47; Birkeland 1999: 11). For example, poorly sorted samples containing particles of diverse sizes, including many larger ones, are often indicative of the kind of brief, but highly energetic, colluvial processes that may have been active at the site, while well-sorted samples composed entirely of sands, silts or clays may be indicative of lower energy alluvial deposition. Prevalence of different depositional processes can inform on issues like availability of water in the site's vicinity. The erodibility of sediment and soil, or the ease at which it can be entrained and transported, is influenced by several factors, including soil structure and consistency, but is also associated with texture (Gerrard 2000: 22).

2.4.3.2 Carbon Content Analysis Background

Carbon content analysis is performed in order to determine the carbon content of samples, which is associated with the organic content of soils. Soil organic matter is a dynamic component of soil that influences many of its properties. Soil organic matter originates mainly from plant tissue, as well as animal contributions from waste and decay (Brady and Weil 2002: 499-500). Carbon used by living plants in the process of photosynthesis becomes incorporated into the soil once the plants die and their plant tissues decay (Brady and Weil 2002: 20). Approximately 48 – 58% of the total weight of soil organic matter is composed of carbon (Nelson and Sommers 1982: 542). Determining carbon content can help to identify buried soil horizons within cores like those taken for this study. In particular, A-horizons are higher in soil organic matter and therefore have higher levels of carbon. There is evidence that as soils are buried and biotic activity ceases the level of carbon decreases significantly (Holliday 2004: 285-286). Despite this, carbon content relative to other horizons within sediment sequences remains a useful compliment to other means of identifying buried A-horizons and inferring conditions under which they developed.

Inorganic carbon content in soils also affects several aspects of soil productivity including pH, structure, and texture (Brady and Weil 2002: 413-415; Gerrard 2000: 43) and can be affected by variables such as climate (Gerrard 2000: 95). The inorganic carbon content of the samples is determined by subtracting the organic carbon value from that of the total carbon. Carbonates are the primary source of inorganic carbon in soils. As discussed below, they can occur in primary or secondary context within soils and sediments. Determining the carbonate content of soil/sediment is part of the standard investigation of soils, informs on the chemistry of the soil/sediment, and can contribute to paleoenvironmental research (See 4.3.4.1 Stable Carbon Isotope Background*)*.

There are a number of different ways of conducting carbon content analysis, but an automated system that directly measures carbon products liberated from combusted sediment samples allows for increased consistency of results, which is important for comparisons between among samples. The LECO-SC632 Sulfur/Carbon Determinator used in this carbon content analysis works using a dry combustion system, with infrared detection of the carbon dioxide gas liberated by elevated temperatures within a ceramic furnace tube into which oxygen is directly introduced for efficient and complete combustion (LECO 2012). Testing for organic carbon is done at a lower temperature of approximately 815ºC, at which any organic matter in the sample is combusted. When the process is repeated to measure total carbon content, the furnace temperature is raised to 1100ºC, at which point any carbonates in the samples are combusted (R. de Freitas, personal communication 2011; Wang and Anderson 1998).

2.4.3.3 Stable Carbon Isotope Analysis Background

Stable isotopes are arguably one of the most important and informative tools to understanding ecological interaction, whether in the present or the past (Dawson et al. 2002: 508). They can be used in numerous ways across a diverse array of disciplines, including, but not limited to, monitoring pollution events, tracking animals' food sources, identifying plants' water sources, determining past human diet, and reconstructing past climates (DeNiro 1987; Scrimgeour and Robinson 2004: 381).

During photosynthesis, plants convert light energy from the sun into stable chemical energy using water and carbon dioxide from the atmosphere (Hohmann-Marriott and Blankenship 2012: 4). This process is known as carbon fixation and results in the integration of atmospheric stable carbon isotopes into plant tissues. There are three carbon isotopes, carbon-14 (^{14}C), carbon-13 (^{13}C) and carbon-12 (^{12}C), which occur in certain proportions in various contexts in the earth's atmosphere and on its surface, including in living organisms. As stable carbon isotopes participate in chemical reactions, reaction rates differ based on differences in the weight and size of the carbon isotopes (van der Merwe 1982: 596). This process of heavier isotopes being taken up at a slower rate and lighter ones more quickly is known as fractionation. It results in the isotope ratios of the products of the reaction or series of reactions differing from the ratio of the reactants (DeNiro 1987: 182). Stable carbon isotopes are measured as a ratio of ^{13}C to ^{12}C.

These values are determined by running samples through a mass spectrometer, which separates charged atoms and molecules on the basis of their mass differences. The basic premise of mass spectrometry is to generate ions from inorganic or organic compounds, separate those ions based on their mass/charge ratio, and then detect their abundance (Gross 2011).

Once the ratio of ^{13}C to ^{12}C of a sample has been determined, it is compared against a universal standard using the formula:

$$\delta^{13}C(\%) = \left(\frac{^{13}C/^{12}C_{sample}}{^{13}C/^{12}C_{standard}} - 1 \right) \times 100$$

The standard used for carbon isotopes is derived from a piece of Cretaceous marine fossil, *Belemnitella americana,* from the Pee Dee formation in South Carolina. This piece of shell is an ideal standard because its ratio of ^{13}C to ^{12}C is higher than nearly all other natural carbon-based materials (van der Merwe 1982: 596); this is why $\delta^{13}C$ values calculated by the above formula are almost always negative. The original standard, known as the Pee Dee Belemnite (PDB), itself has long since been exhausted, but the National Bureau of Standards has created a replacement standard (DeNiro 1987: 182; van der Merwe 1982: 596). While this replacement is not identical to the PDB standard, the degree to which it differs has been calculated in order to allow all samples to be corrected back to values relative to the original PDB.

Terrestrial plants are defined as C_3, C_4 or CAM ("crassulacean acid metabolism") based on the metabolic pathway they follow during photosynthesis. During photosynthesis, C_3 plants incorporate carbon dioxide into organic matter to form a 3-carbon compound as the first stable compound (van der Merwe 1982: 596). During this process, C_3 plants discriminate against carbon dioxide containing ^{13}C, the heavier of the stable carbon isotopes. Instead, they take up more carbon dioxide containing the lighter isotope, ^{12}C, which results in a low ratio of ^{13}C to ^{12}C and a relatively low $\delta^{13}C$ value.

C_4 plants, on the other hand, convert carbon dioxide into dicarboxylic acid, which is a 4-carbon compound. C_4 plants have a higher $\delta^{13}C$ value because the enzyme they use to create this compound does not discriminate against $^{13}CO_2$ (Boutton et al. 1980; Herz 1990: 590). C_3 plants are most common and include all trees, most shrubs and many grasses. Examples of C_3 plants include wheat, rice, beans, tubers and nuts. The less common C_4 plants include some shrubs and most drought tolerant grasses, including maize, teosinte, amaranth, and sugarcane. CAM plants are able to use either enzyme, depending on their environment and whether they take up carbon dioxide during the day or at night. Examples of CAM plants include agave, yucca, pineapple, and prickly pear (DeNiro 1987). This adaptability results in variable $\delta^{13}C$ values, but these types of plants are generally found at lower latitudes, where higher temperatures and aridity are common. This is not the case in the present study area and is therefore not a concern.

The ratios of stable carbon isotopes, as mentioned, are recorded as $\delta^{13}C$ values. Conveniently, there is no overlap between the range of $\delta^{13}C$ values for C_3 and C_4 plants, even though the $\delta^{13}C$ value for a C_3 or C_4 plant is somewhat dependent on the different environmental conditions that the plants are subject to. The range of $\delta^{13}C$ values for C_3 plants is -20‰ to -35‰; and for C_4 plants the range is -9‰ to -16‰ (van der Merwe 1982: 598). The average values in each range are -13‰ for C_4 plants and -27‰ for C_3 plants.

When terrestrial plants are consumed by either animals or humans, the isotopic signature of the plants consumed is passed onto the consumer, making it possible to determine the ratio of C_3 and C_4 plants that made up past diets (van der Merwe 1982: 599). There has been some attempt to determine past environments by using isotopic signatures preserved in the faunal remains of grazing animals to infer the proportion of C_3 and C_4 plants in the area where they would have grazed. This is turn can produce information on the climatic conditions that the plants would have grown in. It is important to note, however, that the mobility of grazing animals results in a less direct measure of plant communities, because the animals may travel long distances across landscapes while grazing, integrating a variety of plants from various seasonal sources and environmental conditions.

The isotopic signature is not only passed on to the consumer when plants are consumed, but the signature is also preserved in the soils on which the plants grow. When plants die and begin to decay, their tissues contribute to the process of pedogenesis (soil formation). Decomposing plant tissues are continually broken down as the soil is actively forming. As a result, the stable carbon isotope signatures of the plant community are incorporated into the organic component of the underlying soil. This process of decomposition is associated with some fractionation, although the changes are very small (approximately 1 to 2‰) and are not substantial enough to affect the calculations used to determine proportions of C_3 to C_4 plants based on $\delta^{13}C$ values (Ambrose and Sikes 1991: 254; Cerling et al. 1991: 297).

Some studies using stable carbon isotope analysis of buried soils for paleoenvironmental reconstruction have focused on the soil organic matter, while others have looked at the pedogenic carbonates (Cerling et al. 1989; Bettis et al. 2009). Like soil organic matter, pedogenic carbonates are formed through the processes of soil formation and inherit stable carbon isotope ratios from the plants under which soils form (Mermut and Landi 2006: 1551). This is because, as plants grow, the carbon dioxide from their respiration results in the formation of pedogenic carbonate through the plants' root systems. These carbonates are generally found in the upper horizons of well-developed, dry soils with good drainage and vegetation. However, pedogenic carbonates can be moved to lower horizons by downward leaching of dissolved carbonates (Bettis et al. 2009: 19). The $\delta^{13}C$ values from pedogenic carbonate samples vary from those from soil organic matter samples, because the formation of pedogenic carbonates is mediated by plant metabolism, causing carbon fractionation that elevates $\delta^{13}C$ values in pedogenic carbonate samples approximately 14 to 15‰ above the values for soil organic matter (Nordt 2001: 425). This method of analysis is most useful in areas with considerable accumulation of pedogenic carbonates, unlike the current study area; this is why soil organic matter was the focus of the stable isotope analysis in this study.

Stable carbon isotope analysis of buried soil samples is useful because it informs on the ratio of C_3 and C_4 plants in vegetation communities present at the times when those soils formed. This method of investigation provides archaeologists with a valuable resource for determining the record of changing plant communities in specific regions through periods of climate fluctuation. The use of stable carbon isotope analysis in paleoenvironmental reconstruction is "particularly effective in semiarid to sub humid climates where plant communities have experienced shifts in the ratio of C_3 to C_4 species" (Nordt 2001: 420). Relative to C_3 plants, C_4 species are usually adapted to warmer temperatures and drier conditions in both their photosynthetic pathway and leaf anatomy. Thus, changes in the proportions of C_3 to C_4 species in past plant communities is an important indicator of climate change, because with increased temperature and deceased moisture, previously C_3 plant communities may be supplanted by C_4 species dominance, or vice versa.

Areas that experience relatively consistent periods of sediment deposition are ideal for stable carbon isotope analysis of buried soil organic matter. Following sediment deposition via overbank flooding, for example, pedogensis occurring on a once-stable land surface ceases. The plant community is no longer able to grow once inundated by new sediments. If the new land surface remains stable, pedogenesis may begin again, resulting in the growth of a new plant community reflective of the contemporaneous climate conditions. If this pattern is repeated, it creates a series of buried soils, or A-horizons, which provide pockets of soil organic matter that contain evidence of the climate conditions under which each developed. There is, however, some risk of diagenesis of the organic matter within these buried soil horizons. Degradation of the organic component may leave insufficient sample for stable carbon isotope analysis to be effective, or may selectively remove one of the stable carbon isotopes, producing a distortion of the results. Despite this possibility, many studies utilizing stable carbon isotope analysis on soil organic matter of buried soils have successfully been conducted (e.g., Ambrose and Sikes 1991; Bekele and Hudnall 2003; Biedenbender et al. 2004; Boutton et al. 1994; Cerling et al. 1991; de Freitas et al. 2001; Feggestad et al. 2004; Fredlund and Tieszen 1997b; Kelly et al. 1993; Kelly et al. 1998; Landi et al. 2003a; Nordt et al. 1994; Robertson 2006).

Stable carbon isotope analysis of organic matter in soils formed under past plant communities has therefore become increasingly useful in the study of paleoenvironment and paleoclimate. Across the Great Plains of North America, stable isotope analysis of soils has been used to investigate paleoenvironment and paleoclimate in specific regions. There have been several climate shifts that have been described generally for the Great Plains, but regional paleoenvironmental reconstruction has resulted in some more specific definition of climate episodes for regions within the area.

In Central Texas, Nordt et al. (1994) made use of stable carbon isotope analysis of soil organic matter collected from buried soils in order to refine previously defined climate trends in the area, this work resulted in an outline of the shifts in vegetation due to climate change over the past 15 000 years. Prior to 11 000 years ago, plant communities in the area were made up of approximately 45 to 50% C_4 plants, indicating a relatively cool and wet climate. Between 11 000 to 8 000 years ago, an increase in C_4 plants correlated with the transition to warmer, drier climate conditions associated with the beginning of the Holocene. During the peak of middle Holocene warming and drying, about 6 000 to 5 000 years ago, mixed C_3/C_4 grasslands were replaced by C_4 dominated plant communities as the prairie environment expanded. Around 4 000 years ago there was a decline in the proportion of C_4 plants, and a return to ratios similar to pre-Holocene plant communities. This reflects a return to cooler, wetter conditions, which have remained relatively constant ever since (Nordt et al. 1994).

In Colorado, stable carbon isotope analysis of soils has been conducted at the Central Plains Experimental Range (Kelly et al. 1994). This study again determines ratios of C_3 and C_4 plants using samples from soil organic matter in order to determine climate change throughout the Holocene. This area includes incredibly well developed A-horizons, with uninterrupted soil development that spans much of the Holocene. The assumption is made that these A-horizons gradually increase in age with depth and that stable carbon isotope analysis of soil organic matter from progressively greater depth within these A-horizons reflects the C_3/C_4 plant ratio through time (Kelly et al. 1994: 236). This is considered to be a "continuous or uninterrupted record of the Holocene vegetative history at the site", but the potential for vertical mixing within the horizon is not fully appreciated (Kelly et al. 1994: 236; Robertson 2006).

There have been stable isotope analysis studies of soil conducted on the grasslands throughout Saskatchewan. Attempts to determine the gradient between grasslands and forest environments have utilized stable isotope analysis of well-developed soils across the province (Landi et al. 2003). The use of stable isotopes in looking at forest/grassland transitions and boundaries is based on the fact that all trees use the C_3 photosynthetic pathway, whereas about 50% of grasses use the C_4 pathway. This analysis is based on the fundamental assumption that "environmental conditions necessary to sustain forests differ from those under which grasses are dominant" (Kelly et al. 1998: 61). Research has also been conducted on the variation of $\delta^{13}C$ values in pedogenic carbonates and organic matter in differing regional environments of Saskatchewan's landscape (Landi et al. 2004). The rate at which carbon accumulates in soil is not constant and is influenced by factors such as environment, vegetation, climate and the water table (Landi et al. 2003a: 407; Kelly et al. 1993: 235). Stable isotope analysis of pedogenic carbonates across the boreal grasslands and forest regions of Saskatchewan show a progressive decrease in values, or heavier ratio, from southwest to northeast across the region. This translates into decreasing representation of C_4 plants in the vegetation along the same southwest to northeast transect (Landi et al. 2003b). With fluctuations in past climate, the gradation of C_3/C_4 plant proportions in vegetation across the province would have shifted, making this another advantageous tool for studying paleoclimate through soils formed under past climatic regimes.

2.4.3.4 Phytolith Analysis Background

Phytoliths are rigid microscopic bodies of hydrated silica ($SiO_2 \cdot H_2O$) that are formed within living plant tissues and are preserved following the death and decay of the plant due to their inorganic composition. The study of phytoliths began in 1835 when a German botanist published a report on phytoliths in living plants. The first archaeological applications of phytoliths were explored in the early twentieth century when researchers were able to identify grain phytoliths from ceramics found in Europe and Turkey (Piperno 1988). The use of phytolith analysis in paleoenvironmental research began in the 1970s, but in the mid-1980s Fredlund and Kurmann were among the first to demonstrate the particular value of phytoliths from buried soils and sediments on the Great Plains, where pollen is rarely preserved (Piperno 2006: 2-4). The use of phytoliths as proxy indicators of past climate and environment has continued developing over the past decades as an important tool for archaeologists. Phytoliths are useful to archaeologists because they are ordinarily inorganic material and therefore preserve well in the soil organic matter beneath once living-plant communities, except in some cases of highly alkaline soils. Phytoliths are arguably "the most durable terrestrial plant fossils known to science" (Piperno 2006: 5).

The majority of phytoliths range in size from 20 – 200 μm, but they can be anywhere from 2 – 1 000 μm (Schaetzl and Anderson 2005: 649). Hydrated silica present in groundwater is taken up by plants and is then deposited in the cells and intercellular spaces of the plant's tissues (Rovner 1983: 226; Bozarth 1993: 95). The silica that is deposited by the plants is in the form of amorphous opal A, with a few other trace minerals. This is why phytoliths are commonly referred to as opal phytoliths (Rovner 1983:226). Because the hydrated silica fills in microscopic spaces within different parts of the plant, such as the leaves and stem, the resulting phytoliths assume the size, shape and configuration of the cell or intercellular space in which they form. The shapes of phytoliths are dictated by two factors: the type of cell in which or around which the silica accumulates and the location of those cells within the plant (Piperno 2006: 24). This results in variation of the morphology of phytoliths within and between plant species (Brown 1984: 345; Boyd 2005: 357; Pearsall 2000: 355).

It is not entirely known why plants produce phytoliths. It has been hypothesized that their production has to do with maintaining rigidity of the plant to prevent wilting or as a defence mechanism against insects, fungal infection, or compression (Rovner 1983: 228; Piperno 2006: 12). Not all plants produce phytoliths, and not all phytolith-producing plants generate them in the same quantities. For example, flowering plants, or angiosperms, the most diverse group of land plants, are traditionally divided into two classes: dicotyledons and monocotyledons. Dicotyledons, which include most varieties of broadleaf, or deciduous trees and shrubs, tend to produce few phytoliths (Pearsall 2000: 370-374). Monocotyledons, in comparison, include members of the Poaceae family, or grasses, which produce consistently high numbers of phytoliths. There are, however, exceptions in both cases. For example, there are some families classified as monocotyledons that produce no phytoliths (Pearsall 2000: 361).

The Great Plains is one of the world's largest expanses of grasslands and has also been the subject of numerous seminal phytolith studies. Although the current landscape of the Great Plains has been shaped considerably by agriculture, the native prairie species that once thrived can be categorized into three main areas. Starting in the foothills of the Rocky Mountains, the western area of the Great Plains is home to the drought-tolerant short grass species. The aridity of the western landscape is due to the rain shadow of the Rocky Mountains. Moving eastward, moisture content gradually increases. This once supported communities of tall grass prairie, although in modern times these have all but disappeared from the landscape having lost more than 97.5% of their historical extent (Koper et al. 2010). In between and extending north of the two, lies a transitional zone of mixed grasses containing an ecologically diverse community of both short and tall grass species. Along the north-south axis of the Great Plains, a temperature gradient also affects the distribution of grassland species with more drought tolerant species dropping in number toward the north, lending to dominance of mixed grass prairie across the Northern Plains.

Boundaries between North American prairie grasslands and surrounding forest areas have shifted during periods of climate variability in the past. The first use of phytolith analysis in paleoenvironmental studies was in order to attempt to identify this shift. Soil scientists compared bulk quantities of phytoliths in order to determine periods in the past when trees encroached on grassland communities (Carbone 1977; Domaar and Lutwick 1969). The relative absence or low numbers of phytoliths may be indicative of forested environments, whereas high phytolith concentrations may indicate grassland vegetation. More recent studies have determined that although trees do produce fewer phytoliths than grasses, it has been underestimated as to how many phytoliths trees actually do produce (Piperno 1988:5; Rovner 1971:345). It appears that the phytoliths produced by trees are smaller and more fragile than their grass counterparts, which may result in the lack of recovery from forested areas.

The dominance of grassland on the Great Plains, combined with the consistently high number of phytoliths produced by members of the grass family, make this region and its grass species particularly amenable for phytolith research. The Poaceae, or true grass, family includes over 10 000 species (Bozarth 1993:95; Piperno 2006: 27), which, in addition to producing abundant phytoliths, also produce an especially complex array of phytolith forms (Pearsall 2000: 365; Piperno 2006: 27; Rovner 1983: 228). Phytoliths deposited in the specialized epidermal short-cells found in grasses are exceptionally useful because they are heavily silicified making them especially resistant to dissolution once buried. Furthermore, they conform to the distinctive shapes of these morphologically variable cells, making them somewhat diagnostic of various grass taxa (Fredlund and Tieszen 1994: 323; Bozarth 1993: 95). Forms of phytoliths other than the short-cell variety, i.e., phytoliths formed elsewhere in the plant, are generally less effective in discerning grass taxa because they are more fragile and preserve less well. Additionally, they tend to be less distinctively shaped, with forms that are common to many grass and non-grass taxa. (Piperno 2006: 28).

Current taxonomic classification of Poaceae includes twelve subfamilies. Three of these subfamilies, Pooideae, Panicoideae, and Chloridoideae, produce some of the most well documented phytoliths and are also dominant taxa in the grasslands of the Great Plains. Specifically, Pooideae species are C_3 grasses that thrive in the relatively cool, wet conditions of northern and central mixed grassland; Panicoideae species include many C_4 varieties that occur in large numbers in the tall grass prairie that lies to the south and east, and Chloridoideae species are C_4 grasses that dominate in the hot, dry conditions of the short grass prairie that lies to the south and west. Their short-cell phytoliths are produced in shapes that are not exclusive to or strictly diagnostic of any one grass subfamily, but are considerably more common in a particular subfamily and much rarer in the others. Proportions of these phytolith shapes can therefore be used to determine whether mixed grass, tall grass or short grass communities dominated the landscape at different times in the past by analyzing the assemblages of phytoliths preserved in buried soils formed at these times; this, in turn, makes it possible to reconstruct the climatic conditions which supported these distinctive grasslands.

The subfamily Pooideae includes 160 genera of grasses, which are divided into two supertribes (Poodae and Triticodae), and seven tribes. These plants are found to occur mostly in high elevation areas, with cooler temperatures. Some examples of Pooideae plants include cereal grains such as barley, rye, oats, wheat and most northern temperate lawn and pasture grasses (Piperno 2006: 28; Twiss 1992: 117). Chloridoideae is divided into eight tribes and includes many of the short grasses. Chloridoid grasses occur in regions where temperatures are warm and available soil moisture is low, such as prairies and savannas (Piperno 2006: 28). In general, areas rich in these drought-adapted short grasses have a mean temperature in the coldest month of more than 10ºC (Twiss 1992: 117). The third main subfamily of grasses that is important in phytolith research on the Great Plains is Panicoideae, which is divided into two supertribes, Andropogonodae and Panicodae. This subfamily consists of tropical tall grasses, such as maize, sugarcane and sorghum, as well as the species that dominate modern tall grass prairies communities. They tend to grow well in areas with warm temperatures and high levels of available soil moisture, such as tropical and subtropical areas (Twiss 1992:119).

These three groups of plants, Pooideae, Chloridoideae, and Panicoideae, are instrumental in the use of phytoliths for paleoenvironmental reconstruction in the Great Plains region. Proportions of the dominant phytoliths associated with each group can be extracted from old and/or buried soils and used to identify the dominant grasses that contributed phytoliths to the development of that soil. Because each subfamily has adapted to such different climate and environmental conditions, phytolith studies can yield "an accurate picture of grassland subfamily composition…[which] provides a sound basis for studying past vegetation, rainfall, and temperature" (Piperno 2006: 33).

Over the past two decades, considerable research has been conducted in an effort to standardize phytolith nomenclature. Unlike pollen, there is no standardized scheme for terminology or classification of phytoliths. In part, this is because, while many pollen forms can be directly linked to particular plant taxa at the family, genus, or even species level, phytolith forms commonly occur across multiple taxa (Piperno 2006: 25-26). As a result, phytoliths are generally described based on either their geometric shape or surface attributes or the plant tissue from which certain phytolith forms originate. What complicates the study of phytoliths is that several distinct shapes can be formed by different tissues within a single plant species, and one or more of these shapes can be formed by the same tissues in other species of plants (Piperno 2006: 27). Single species of plants can produce a wide range of phytoliths in different shapes and sizes; this is known as the concept of "multiplicity" (Twiss 1992: 116; Fredlund and Tieszen 1994: 323). On the other hand, particular shapes of phytoliths can occur in many different species, known as "redundancy" (Twiss 1992: 116) Therefore, relatively few phytoliths are diagnostic of particular plant taxa.

In 1969, Twiss et al. were the first to propose a broad typological scheme that relates these three dominant subfamilies with categories of short-cell phytoliths in the North American Great Plains. In this classification system, the authors identified diagnostic festucoid (pooid) phytoliths as circular, rectangular, elliptical or oblong forms that are common in domestic grasses growing in humid regions (Twiss et al. 1969:109). They also identified saddle-shaped phytoliths as diagnostic of chloridoids, or short grasses, and cross- and dumbbell-shaped phytoliths as diagnostic of panicoids, or tall grasses. Stemming from this seminal work, there have been considerable attempts to refine the classification scheme.

Fredlund and Tieszen (1994) define ten basic morphotypes of short-cell phytoliths from their research of phytoliths on the Great Plains, using a synthesis of other phytolith classification systems, including Twiss et al. 1969, as background. These ten morphotypes are: conical, keeled, pyramidal, crenate, Stipa-type, simple-lobate, panicoid-type, cross, other lobate forms and saddles (Figure 2.9) (Fredlund and Tieszen 1994: 324).

Conical, keeled, pyramidal and crenate morphotypes are all produced in high numbers by Pooideae grasses, although they are also produced in lower numbers by other grass subfamilies. High ratios of these morphotypes would be indicative of plant communities that thrive in environments with cool temperatures and high moisture levels. Fredlund and Tieszen (1994) identify two morphytypes of saddles that are indicative of Chloridoideae family short grasses,

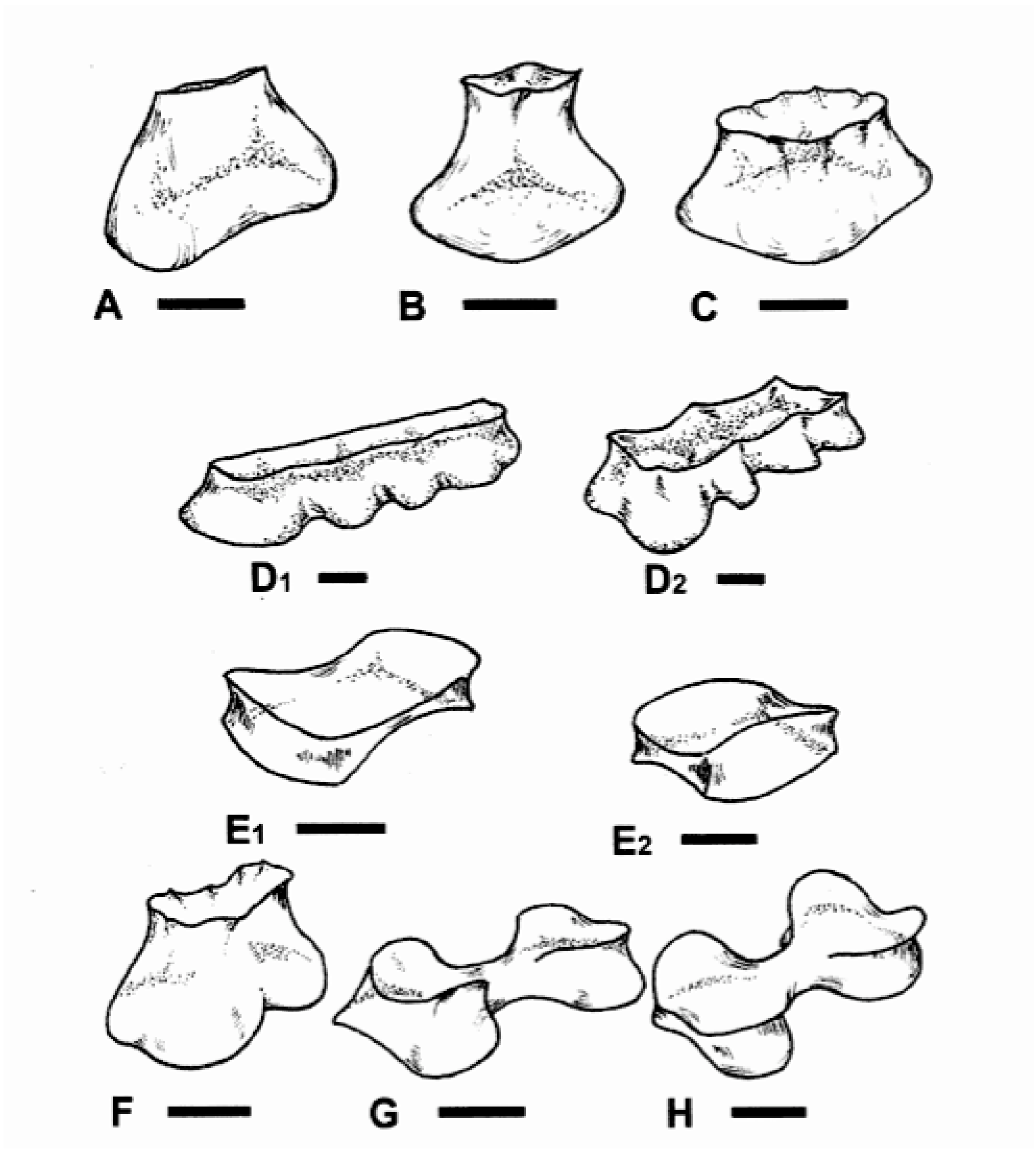


Figure 2.9. Ten basic morphotypes of typical Poaceae plant phytoliths as classified by Fredlund and Tieszen (1994: 326). A. Keeled; B. Conical; C. Pyramidal; D1 and D2. Crenate; E1 and E2. Saddle; F. *Stipa*-type; G. Simple Lobate; H. Panicoid-type.

representative of short grass communities and hot and arid environments. Simple lobate and panicoid-type morphotypes are characteristic of Panicoids, or tall grasses that thrive in warm temperatures with high available soil moisture (Bozarth 1993: 95; Fredlund and Tieszen 1994; Alam et al. 2009: 509). While these morphotypes are indicative in high numbers of each of these groups, they can still be produced by the other subfamilies. In order to determine the general subfamily that dominated a plant community, it is important to determine ratios of phytoliths within a large assemblage.

Fredlund and Tieszen (1994) demonstrate the effectiveness of phytolith analysis on the Great Plains. Using 50 samples taken from a variety of locations spanning the west-east moisture gradient and north-south temperature gradient, Fredlund and Tieszen (1994: 328) demonstrate the correlation between phytolith assemblages found in contemporary soils and the identified grassland communities growing on them. This research found increasing Panicoid grasses and phyotlith types present in samples towards the east, where precipitation also increases. Frequency of Chloridoid grasses and phytolith types, associated with the higher temperatures and decreased moisture of the southwestern portion of the Plains, increased in samples moving southward (Fredlund and Tieszen 1994: 333). This research also demonstrates that phytolith assemblages from soil samples reflects regional grassland composition, rather than the vegetation growing immediately at the soil sampling locations (Fredlund and Tieszen 1994: 321, 331). The classification scheme used in this research "provided an empirical quantitative means for calculating the contribution of climatically sensitive grass subfamilies" (Fredlund and Tieszen 1994: 333-334). The location of the Red Tail site at the northern end of Great Plains and the mixed grassland community currently dominant at the site make Fredlund and Tieszen's research a useful model for the present study. Because phytolith analysis of buried soils produces information on past plant communities, this technique pairs well with stable isotope analysis, the three main subfamilies identified by Fredlund and Tieszen's technique can be related to the photosynthetic pathways identified by stable carbon isotope analysis. Results from phytolith analysis therefore complement the information gathered through stable isotope analysis and sediment analysis to give a more robust, multi-proxy interpretation of the paleoenvironmental conditions throughout the history of the site.

2.4.3.5 Radio Carbon Dating Background

Radiocarbon dating is an essential tool used by archaeologists in order to determine the age of artifacts unearthed during excavation. It can be used to date a number of organic materials including, but not limited to, bone, wood or shell. Through the process of photosynthesis, plants absorb both the stable carbon isotopes, carbon-12 (^{12}C), carbon-13 (^{13}C), and the unstable form, carbon-14 (^{14}C). These isotopes are passed to other living things that consume the plants. Once these organisms die the carbon isotopes are no longer replenished and the ^{14}C begins to decay at a known rate (Lowe and Walker 1997: 240-241). The procedure of radiocarbon dating measures the amount of radioactive ^{14}C remaining in a sample, producing an uncalibrated radiocarbon date. Dates are then calibrated to produce a calendar date for the death of the sampled organism based on known fluctuations of carbon isotope proportions in the atmosphere through the past. The calibration of the radiocarbon dates reported in this study was conducted using standard methods by the laboratory that produced the dates, Beta Analytic (see Appendix C).

The preferred samples for the most accurate radiocarbon dating in geoarchaeological contexts are charcoal, wood or plant macrofossils. Because of the limited size of sample recovery during coring, the probability of finding one of the preferred sample types to send for radiocarbon dating is low. Instead, soil organic matter can be used to determine a date during which the buried soils were actively undergoing pedogenesis.

Radiocarbon dates obtained from this type of sample can be problematic due to the fact that pedogenesis is an ongoing process (Holliday 2004: 178-179; Lowe and Walker 1997: 247; Wang et al. 1996). Radiocarbon dating of soil organic matter can provide the mean residence time (MRT), or the average time the soil was active, as well as a minimum age for when the deposition that preceded pedogenesis ceased (Holliday 2004: 179). This problem is especially pertinent in situations where soils develop over a long period of time. At the Red Tail site, the buried soils are not well developed, indicative of short intervals of time during which the soils was actively undergoing pedogenesis. This situation somewhat mitigates this issue, as dates from samples of these narrow A-horizons should represent averages for fairly limited time intervals (Stafford 1998: 1052). Furthermore, much of the deposition between episodes of pedogenesis at the Red Tail site is alluvial or colluvial. This type of deposition often occurs quickly and results in a fairly large amount of sediment inundating surfaces previously undergoing pedogenesis (Orlova and Panychev 1993: 374). This deposition tends to rapidly end soil formation, preserving the integrity of the soil organic matter as a closed system with respect to carbon addition or loss following the soil's burial (Orlova and Panychev 1993: 375-376).

If the buried soil remains uncontaminated, a radiocarbon date will reflect the MRT of the soil before burial occurred (Holliday 2004: 179).

However, diagenesis of buried soil organic matter can also be an issue. During pedogenesis, decomposition of organic matter occurs rapidly, but contributes to the formation of humus. Humus is the relatively stable component of soil organic matter, which includes the humins, humic acids, and fulvic acids that are left behind after initial decomposition of biotic inputs to the soil (Brady and Weil 2002: 921). This is the component that remains once the soil is buried (Holliday 2004: 179). However, its composition and integrity can be altered following burial of the soil. The humin component of soil organic matter is comprised of long-chain organic molecules that are not soluble in acid or alkali solutions; thus, they resist breaking down and/or moving through the soil profile over time. Fulvic acids are the low-molecular weight component of soil organic matter that is soluble in water regardless of pH; humic acids are intermediate between fulvic acids and humins in terms of molecular weight and can be dissolved by alkali solutions. The humic and fulvic acids in soil organic matter therefore can move through the soil profile over time, contaminating soil organic matter in higher or lower buried soils and creating the opportunity for overly young or old dates. For this reason, they are commonly removed from the sample before dating using an alkali solution, isolating the humin fraction and providing the greatest likelihood of a radiocarbon date on organic matter original to the sampled soil. However, the humin fraction can also be contaminated by roots extending downward from higher soil surfaces or other intrusive organic matter moved from above or below by processes such as bioturbation. Ideally, both the humin fraction and the humic and fulvic acids are dated separately to provide checks to assess if any of these issues are at play. But, due to monetary constrains, this was not possible in this study. Instead, the samples were subjected to an acid-base-acid pretreatment designed to remove the most mobile and therefore least reliable organic fractions, leaving the humin component for dating. Even under these circumstances, radiocarbon dating of soil organic matter can still "help in establishing the broad outlines of a soil chronology and a site chronology" (Holliday 2004: 179). Given the absence of other dateable material from the cores taken from the Red Tail site, radiocarbon dating soil organic matter provides the opportunity for obtaining estimated ages of soils that developed over relatively short periods of time.

2.5 Current Climate and Ecology

Modern climate conditions in the Saskatoon area are an important component in understanding the physical characteristics of the area. The Saskatoon area has a cold, subhumid continental climate, with substantial variations in temperature and dry conditions (Maybank and Bergsteinsson 1970: 22; Walker 1992: 4). Temperature and precipitation averages from Environment Canada are calculated using values taken between 1971 and 2000 at the Saskatchewan Research Council facility on the University of Saskatchewan campus, located approximately 8 km from Wanuskewin Heritage Park.

The average temperature in the coldest month, January, is -16.4°C, while in the hottest month, July, the average temperature is 18.3°C. Temperatures in January range from -21.6°C to -11.1°C, and from 11.5°C to 25°C in July (Environment Canada 2010b). Five months of the year have average temperatures below freezing, making for a long, cold winter (Maybank and Bergsteinsson 1970: 22). The driest and wettest months for precipitation are February and June respectively, with an average of 13.1 mm of precipitation in February and 60.5 mm in June. The average total annual precipitation for each year between 1971 and 2000 is 348.3 mm (Environment Canada 2010a). In the Saskatoon area, about 30% of this annual precipitation falls in the form of snow. This equates to a mean annual snowfall of approximately 106 cm, which contributes to the annual average runoff of about 50 mm (Atlas of Saskatchewan 1999: 106; Environment Canada 2010a). Annual runoff, highest in spring with the melting of snow accumulated through the winter, contributes to the replenishment of ground water, possible flooding and slope instability along the river valley (Maathuis 1999: 127).

2.5.1 Flora and Fauna

Vegetation contributes to both soil development and surface stability. Erosion of a surface varies with changing vegetation type and density because the root networks increase soil strength, granulation and porosity (Selby 1993). Vegetation cover is also one of the most important factors in soil formation as decaying plant organic matter contributes to the process of pedogenesis (Saskatchewan Land Resource Centre 1999: 129).

The Wanuskewin Heritage Park area is currently categorized as falling near the boundary between the Aspen Parkland and Moist Mixed Grassland ecoregions (Figure 2.10) (Sask Herbarium 2008). The Aspen Parkland is a transitional zone between the boreal forest to the north and the grasslands to the south and was once characterized by an abundance of trembling aspen, oak groves, mixed tall shrubs, and intermittent fescue grasslands. The natural vegetation of the area has been altered with the appearance of Europeans settlers, who brought along foreign species of plants and introduced domesticated landstock grazing in the area (Thorpe 1999: 134). Farmland now dominates the ecoregion, while unaltered areas are often used for livestock grazing (Acton et al. 1998: 27). Livestock grazing has been absent from the park since the mid-1980s, resulting in some reestablishment of more native species.

Farmland also now dominates the Mixed Moist Grassland ecoregion. This ecoregion marks the northern extension of grassland in Saskatchewan and is characterized by undulating to hummocky topography including numerous undrained depressions (Sask Herbarium 2008). These sloughs are often home to small aspen groves. The dominant soils found beneath the Aspen Parkland and Mixed Moist Grasslands are dark brown chernozems, the primary soil across the grassland regions of Canada. Dark chernozemic soils are characterized as "well to imperfectly drained soils having surface horizons darkened by the accumulation of organic matter" (Soil Classification Working Group 1998: 61). These organically rich soils are highly fertile, hence the dominance of agriculture in the area.

As with the flora, the fauna in the Wanuskewin area has been altered over time with the introduction and extirpation of species. Faunal populations vary due to natural or human induced fluctuations in their food availability, predation or disease (Acton et al. 1998: 26). Prior to European settlement, large numbers of bison grazed freely across the region. Many animals that were once common in the park have since greatly decreased in number or disappeared from the area completely, including, but not limited to, grizzly bears, mountain lions, wolves, swift foxes and wolverines. Animals that remain common in the park include coyotes, raccoons, badgers, red foxes, ermine, weasels, mink, striped skunk, snowshoe hare, white-tailed jackrabbits, whitetail and mule deer, and a variety of rodents (Banfield 1974).

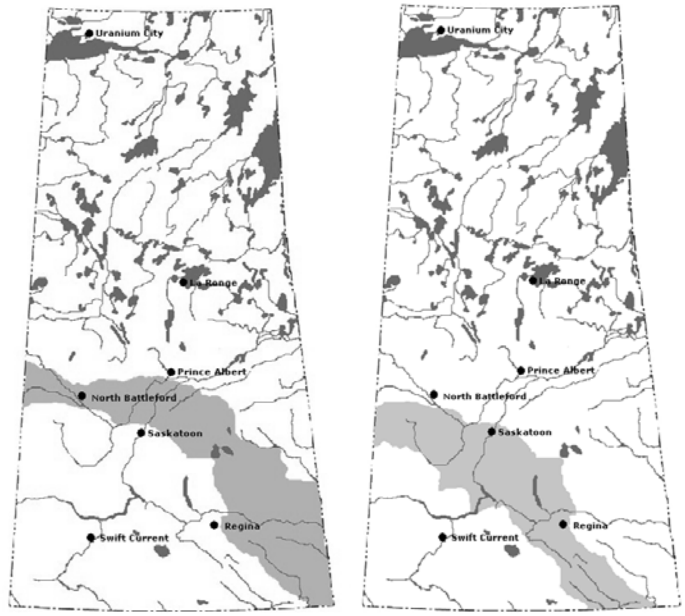


Figure 2.10. Boundaries of the Aspen Parkland (left) and Moist Mixed Grassland (right) ecoregions (Sask Herbarium 2008).

Chapter 3: Culture History Background

3.1 Introduction

Since the retreat of the last glaciers, the Northern Plains have experienced a rich cultural history. The period of human occupation on the Northern Plains prior to European contact (ca. 12 000 to 300 B.P.) can be divided into three main time frames, which are traditionally linked to postulated technological advancement, as well as associated changes in lifeways and subsistence. These divisions are not always clear, making it difficult to construct a definitive timeline. The first to devise a classification scheme for the archaeological record of the Northwestern Plains was William Mulloy in 1958, which has been further adapted and modified by other archaeologists since (see Dyck 1983; Frison 1978; Reeves 1983; Wedel 1961; Wormington and Forbis 1965). These classification schemes divide segments of time into periods, which are then further subdivided into complexes, traditions or phases (Peck 2011: 5).

The Early Precontact Period, dating to approximately 12 000 to 7 500 B.P., is defined by the use of spear points. The Middle Precontact Period, which is further subdivided into the Early Middle, Middle Middle, and Late Middle Precontact Period, is generally dated from 7 500 to 2 000 B.P., and is defined by the reduction in size of projectile points, which is commonly related to the use of atlatl darts. The Late Precontact Period, 2 000 years B.P. until the appearance of Europeans, includes the use of bow and arrows and the development of pottery (Walker 1992: 120). Within each of these periods, archaeological cultures are identified based on assemblages of material remains found during surveys and excavations. Projectile points are particularly useful as diagnostic markers for identifying variation between potentially distinct groups because they are commonly found during excavation and have distinctive traits that can be recorded and compared (Frary 2009: 13). There is, however, considerable debate regarding the defining technological features of these periods. For example, although the Middle Precontact Period is defined by the advent of the use of the atlatl, the use of this spear-throwing device was not impossible with the larger lanceolate points of the Early Precontact Period. However, the organic material the atlatls were made from has simply not been preserved in the region's archaeological record making it difficult to identify the first use of this technology (Bryan 2005: 55-56). While these differentiations have been made for convenience and practicality, they continue to be refined and modified, as new evidence is uncovered.

The development of terminology and demarcation of periods of the cultural chronology of the Northern Plains is illustrated in Table 3.1. It shows that most of the general definitions of periods have remained similar, but as evidence of Middle Precontact occupation increased, Mulloy's original theory of a cultural hiatus was removed. Mulloy posited a hiatus because of the lack of archaeological evidence on the Northern Plains dating to this time. Increasing evidence of continuous occupation has since been discovered, but this remains an important area of continuing research.

Table 3.1. Comparison of select cultural chronologies of the Northern Plains (Cyr 2006: 17; Modified from Walker 1992: 120).

Years (ka BP)	Mulloy 1958		Frison 1978		Dyck 1983	Walker 1992		Cyr 2006	
0.2	Historic		Historic		Historic	Historic		Contact	
0.3	Late Prehistoric		Late Prehistoric		Late Plains Indian	Late Prehistoric		Protocontact	
2.0								Late Precontact	
3.0	Middle Pre-historic	Late	Plains Archaic	Late	Middle Plains Indian	Middle Pre-historic	Late	Middle Precontact	Late
5.0		Early		Middle			Middle		Middle
7.5	Hiatus			Early			Early		Early
10.5	Early Prehistoric		Palaeo-Indian		Early Plains Indian	Palaeo-Indian		Early Precontact (Palaeo-Indian)	
12.0					Pleistocene Hunters				

Particularly in Wanuskewin Heritage Park, precontact groups have returned year after year to take advantage of what has been postulated to be a perpetually lush valley and protective environmental setting (Smith 2012). The concentration of multi-component sites within the Park encompasses approximately the last 6 000 years of the Precontact Period. Because of the concentration of sites, the archaeology within and surrounding Wanuskewin Heritage Park provides an opportunity to examine an extended portion of Northern Plains culture history in a distinct, well-defined geographic area. As discussed in the previous chapter, the changing climate and environment during the latter half of the Holocene would have had considerable impact on these groups. Archaeological material at the Red Tail site ranges from the McKean Complex to recent historic material and therefore, a discussion of the associated archaeological cultures is outlined below. Some additional information on archaeological cultures found elsewhere in Wanuskewin Heritage Park is also provided because the climatic and environmental results provide context for other sites in the immediate area.

3.2 Middle Precontact Period (7 500 – 2 000 years B.P.)

Prior to the Middle Precontact Period, the Early Precontact Period was a time of drastic environmental change in the wake of deglaciation. Highly mobile early groups of Early Precontact people adapted to this dynamic environment and witnessed the extinction of many species they relied on. As new sites dating to this period are found, what is known about the cultures of the Early Precontact Period continues to develop.

The Middle Precontact Period shows further adaptation to environmental changes, with the its first half reflecting elevated temperatures and increased aridity and its second half characterized by a moderation of these warm, dry conditions. This first part of this period is of particular interest because of the paucity of evidence and limited understanding about how archaeological groups adapted to the complex environmental and climatic changes occurring during this time. At one time, it was suggested that these conditions created an environment so inhospitable to human occupation that there was a desertion of the Plains area (Mulloy 1958). Evidence found since the proposition of this theory has suggested that, although overall population may have decreased, occupation of the Plains area persisted (Kornfeld et al. 2010: 114; Robertson 2011; Walker 1999: 25).

As the climate changed, so did the subsistence strategies of those occupying the Northern Plains (Walker 1999: 25). While the pattern of bison centered subsistence continued, the gathering of plant resources appears to increase (Frison 1998: 148). Manos and matates, used in the preparation of plant foods, appear prior to the Middle Precontact period, but during this period they become increasingly common and attain diagnostic forms (Frison 1998: 148).

There is also apparent change in the projectile point types of the Middle Precontact Period. The large spear points of the Early Precontact Period were replaced by smaller and notched points, an adaptation to allow hafting to a wooden shaft sized to be used with an atlatl, or spear-thrower (Dyck 1983: 87, 92; Kornfeld et al. 2010: 106; Kooyman 2000: 119). Distinctive point types define a number of different archaeological cultures living across the Northern Plains during this time of complex change.

3.2.1 Early Middle Precontact Period (7 500 – 5 000 years B.P.)

The Early Middle Precontact Period is associated with the Mummy Cave Series, which was first identified at the type-site in northern Wyoming. A number of different projectile point types are associated with the Mummy Cave projectile point series, but many have not been named due to challenges in assigning them to distinct categories (Kornfeld et al. 2010: 109). Two of the most widely distributed point styles of the Mummy Cave Series are the Bitterroot Side-notched (also known as Northern Side-notched) and Gowen Side-notched (Walker 1999: 25). Bitterroot points have a side notch that is noticeably high on the base, while the Gowen point is described as "relatively nondescript" (Walker 1992: 141; Kooyman 2000: 119). There is a distinct lack of sites containing Mummy Cave material, possibly because the sites have been destroyed by erosion or deeply buried, making discovery difficult and excavation expensive (Dyck 1983: 92; Reeves 1973).

Mummy Cave is the oldest identified material at Wanuskewin Heritage Park (Cyr 2006: 121-124; Pletz 2010: 31). Artifacts were discovered at the Dog Child site, the most northerly site in the Park, located on a terrace on the west side of Opimihaw Creek (Wanuskewin Heritage Park 2012b). Although occupation layers at the Red Tail site have been radiocarbon dated to the time span associated with Mummy Cave, no diagnostic artifacts of this culture were recovered.

3.2.2 Middle Middle Precontact Period (5 000 – 3 000 years B.P.)

The onset of colder climates at the end of the Hypsithermal coincides with what is defined as the Middle Middle Precontact Period (Walker 1999: 25). Two main archaeological cultures dominate this time period, Oxbow and McKean. The Oxbow (4700 to 3800 years B.P.) culture were bison hunters and possibly the first to use tipis as habitation structures (Bryan 2005: 91). Oxbow habitation sites are common especially in Saskatchewan (Kornfeld et al. 2010: 113, Walker 1999: 25). Oxbow subsistence remained bison centered, but the lack of large-scale bison kill sites has resulted in a paucity of information on how bison were procured (Dyck 1983: 96).

The Oxbow projectile point is a side-notched point with a concave base that gives it the appearance of rounded ears. There is a distinct similarity with earlier Mummy Cave material, suggesting a development of Oxbow from Mummy Cave (Peck 2011: 170; Walker 1992: 144). They are stylistically distinct and are sometimes found overlapping with the somewhat later McKean Complex in time and space, leading to the conclusion that McKean was a later invasive cultural group.

Sites showing evidence of McKean Complex (4100 to 3100 years B.P.) habitation are not commonly found on the Northern Plains, in comparison with much more common Oxbow sites, making it difficult to construct a clear understanding of the development of this archaeological culture (Peck 2011; Webster 2004). The McKean Complex was first described by William Mulloy in 1954 at the type-site in Crook County, Wyoming. Excavated in 1951 and 1952, the McKean site gave the first example of a McKean Lanceolate point. The McKean Lanceolate point has an indented base and no shouldering or side-notches (Kooyman 2010: 121). Two other stylistically similar point styles, Duncan and Hanna, occur concurrently with the McKean Lanceolate and are therefore grouped together into the McKean Complex. Duncan points have a stemmed appearance due to wide side notches, while Hanna points are more clearly side notched (Walker 1999: 26). The three point types are sometimes found independently of one another (Dyck 1983: 100) and the relationship among these points remains unclear.

The origins of the McKean Complex on the Northern Plains continue to be a point of controversy amongst archaeologists. Theories include either the migration or in situ development of McKean from preceding groups. Proponents of the migration theory have suggested two main areas of origin: the Great Basin in the Southwestern U.S.A. or the foothills of the Rocky Mountains. Mulloy (1954) draws parallels between the McKean type-site and the Gosiute of the northeastern Great Basin. Excavations such as those at Danger Cave, Utah and Leigh Cave, Wyoming were subsequently used to substantiate this theory based on similarities between subsistence strategies and projectile points (Jennings 1957, Frison and Huseas 1968). Archaeologists in support of an in situ development of the McKean Complex argue for diffusion rather than migration in order to explain similarities between McKean and Great Basin materials (Keyser and Davis 1985; Tratebas 1998). Wright (1995) proposes a theory of direct relationship between Oxbow and McKean. He points to the similar distribution of sites containing assemblages of both Oxbow and McKean, the similarities between their tool kits and the stratigraphic occurrence of McKean components above Oxbow (Wright 1995: 300-332).

Later review and technological comparison of points and subsistence strategy have rendered these arguments less compelling. Wilfred Husted (1969) rejected the theory of a Great Basin origin and instead suggested migration from the foothills and mountains of the Rocky Mountains. This theory was further supported by Leigh Syms (1970) when he plotted radiocarbon dates of McKean sites to determine the origin of McKean migration into Manitoba. The sequentially later dates at sites further away from the Big Horn Basin of northwestern Wyoming illustrated the movement of

McKean groups across the Northern Plains. More recently, Sean Webster's analysis of McKean origins also supported Syms' hypothesis (Webster 2004).

Evidence points to a population that was able to adapt to changing environment and climate. The dynamic environment and climate of the post-Hypsithermal has been argued as the impetus for migration. Increased population pressure may have also contributed to movement away from core areas (Webster 2004). The adaptability of the McKean toolkit and subsistence pattern was likely a factor in their success across the Northern Plains. This adaptability has led some researchers to identify a possible dichotomy between northern and southern McKean assemblages.

Differences in subsistence strategy have been cited as a distinguishing factor between northern and southern assemblages of McKean. It has been argued that the northern assemblages of McKean demonstrate a subsistence strategy more heavily reliant on bison, while a broader subsistence pattern exists in the south (Wormington and Forbis 1965: 190-192). The appearance of stone-lined roasting pits, rather than the previously recorded common simple hearths, is important in the interpretation of McKean subsistence patterns. The stone lining is often interpreted as being indicative of the cooking of vegetable foods, suggesting their increased importance in the diet (Kooyman 2000: 122). Further evidence of increased utilization of plants as a food source includes the greater prevalence of grinding stones. Not only are they more common, but they are also "increasingly uniform and relatively elaborate in their form and production" (Kooyman 2000: 122).

3.2.3 McKean Complex Occupation at the Red Tail Site

Several sites at Wanuskewin Heritage Park include assemblages of McKean Complex artifacts, including Cut Arm, Meewasin, Thundercloud and, of course, Red Tail (Webster 2004). McKean is not the earliest cultural material found within the park, but it is particularly significant because of the time period it represents. McKean occupation at the Red Tail site in particular was detailed in Charles Ramsay's thesis "The Redtail Site: A McKean Habitation in South Central Saskatchewan", completed in 1993. There were at least seven McKean occupations identified at Red Tail, showing some development of the culture through time (Webster 2004: 32-33). This is important for the site's contribution to the theories of the origin and adaptation of McKean to the surrounding environment. Evidence indicates that the site was occupied for short periods of time; five components suggest spring/summer campsites, while others suggest longer occupations spanning multiple seasons (Ramsay 1993; Webster 2004).

The excavation at Red Tail resulted in the largest seed assemblage at a McKean site in the Northern Plains and is the first site to substantiate McKean plant utilization in the Northern Plains (Webster 2004: 73). This is a significant contribution to the previously discussed dichotomy between northern and southern assemblages of McKean based on subsistence strategies.

The artifacts recovered from the McKean occupations at Red Tail mostly comprise lithic debris and tools, but also include two possible grinding stones, a few possible bone tools and fire broken rock. Ramsay also reports 69 features found at the site, including hearths, pits, ash concentrations and charcoal concentrations (Ramsay 1993: 198). Interestingly, in Layer 8 of the excavation a possible house pit was identified. This possible living structure is significant because although no diagnostic artifacts were found at this occupation level, the structure may be similar to house pits found in Wyoming and dated to that region's Archaic Period (ca. 8 000-1 800 yrs B.P.) (Webster 2004: 20). Although not yet confirmed, this discovery could make significant contributions to archaeological understanding of McKean origins and dwellings on the Northern Plains.

Ramsay's analysis of the site materials concludes that varying activities took place at the site during different occupations. The levels vary from single or multiple occupations to a probable single bison kill site found in Layer 10 (Ramsay 1993: 351). Some indications of seasonality are based on maturity of bison specimens and most appear to indicate spring/summer occupations.

3.2.4 Late Middle Precontact Period (3 000 – 2 000 years B.P.)

At the end of Middle Precontact Period, the Oxbow and McKean complexes are replaced by the Pelican Lake Complex (3 600 – 2 800 years B.P.). The definition of the Pelican Lake culture began with the recovery of materials at the Mortlach site, located in south-central Saskatchewan. The projectile points were described as "corner-notched, with oval cross-sections, beveled on the edges and toward the base, widest just above the notches, with the base narrower than the blade and tapered to a long symmetrical point" (Peck 2011: 224; Wettlaufer 1955: 55). Other materials commonly recovered include bifaces, end scrapers and retouched flakes, while faunal remains indicate a heavy reliance on bison. Groups appear to have been larger and more organized than their predecessors, based on evidence of communal bison hunting and processing (Bryan 2005: 111). Although the emergence of bow and arrow technology is often attributed to the beginning of the Late Precontact Period, the small size of some Pelican Lake points suggests the possibility of earlier bow and arrow use (Walker 1999: 26).

Contemporaneous with Pelican Lake, other point types, including Sandy Creek points (2 750 to 2 150 years B.P.) and others that remain unnamed, have been identified at several sites in Saskatchewan (Dyck 1983: 107-108; Walker 1999: 26). They are described as small and thick points with shallow side-notches and indented bases. Sandy Creek is neither commonly found, nor well understood, but they do bear a striking resemblance to the earlier Oxbow points (Dyck 1983: 108-109). No material from these assemblages was found at the Red Tail site.

3.3 Late Precontact Period (2 000 – 300 years B.P.)

The beginning of the Late Precontact Period is traditionally defined by two important technological advancements: the widespread use of the bow and arrow and the introduction of pottery (Frison 1998: 147; Walker 1999: 26). Although not particularly abundant, the first evidence of pottery in Saskatchewan is attributed to the Besant complex (2500 to 1400 years B.P.) (Dyck 1983: 110). Remains of conical pots with sand or grit temper and some decoration impressed using cord or other materials are found among some Besant assemblages (Walde et al. 1995: 18). The Besant complex is also associated with large-scale bison procurement strategies such as buffalo pounds and jumps and is considered one of the most successful and prolific groups of bison hunters in the history of the Northern Plains (Dyck 1983: 113). Besant points are described as mid-sized with side notches that are about twice as wide as they are deep (Kooyman 2000: 124; Vickers 1994: 9). Besant habitation sites include evidence of pole frame structures, as well as tipi rings, indicated by the characteristic circular arrangements of stones, which would have once secured the edges of the tipi (Walker 1999: 26). Within Wanuskewin Heritage Park, diagnostic artifacts from Besant are found at the Meewasin site and the Newo Asiniak site.

While the proficiency of Besant bison hunters resulted in their sites being the most common in Saskatchewan their origins remain unclear. There is evidence of connections to Eastern Woodland groups, including but not limited to woodland-type pottery, bark or mat covered pole structures and possibly burial mounds (Dyck 1983: 115; Walker 1999: 26). Controversy also exists over the classification of another complex known as Sonota. The debate centers on whether Sonota is culturally distinct from Besant (see Neuman 1975, Peck 2011) or if is a derivative of Besant and should only be used to describe the mortuary style (see Dyck 1983, Reeves 1983, Walde et al. 1995). Due to the numerous similarities between Besant and Sonota assemblages and features, and because the use of the term Besant predates Sonota, the latter should only be used to describe the mortuary style that includes the use of burial mounds (Walde et al. 1995).

Besant and Avonlea are two separate complexes frequently found overlapping in time and space. The Avonlea Complex dates between 1750 and 1150 years B.P. The previous reliance on bison and large-scale procurement strategies continue through this complex, but this is the first group thought to solely use bow and arrow technology (McMillan and Yellowhorn 2004: 136). Avonlea points are described as well-manufactured, small, very thin triangular arrow points with side notches and slightly concave bases (Kooyman 2000: 124). Pottery becomes more varied during this period and becomes more common and widespread. Avonlea pottery is found in two distinct shapes, concoidal and globular. It displays one of three main types of exterior finish: net-impressed exteriors, spiral-channeled exteriors and smoothed exteriors (Walker 1999: 26). Compared to Besant, Avonlea sites are less widespread in Saskatchewan. Avonlea material has been recovered from three sites within Wanuskewin Heritage Park, including Amisk, Newo Asiniak and Tipperary Creek (Linnamae et al. 1988: 166-168).

Subsequent to Besant and Avonlea, the Late Precontact Period is complex and several changes are evident, including increases in and movement of populations and the emergence of horticultural practices (Walker 1999: 27). The widespread use of pottery leads to another means of classification rather than the previous almost exclusive reliance on projectile point typology. The Late Side-Notched Series includes the Prairie Side-Notched complex (1200 – 550 years B.P.) and the Plains Side-Notched complex (550 – 170 years B.P.). Prairie Side-Notched points are small, with side notches close to the basal corners (Dyck 1983: 129). Their similarity, both in manufacture technique and raw material, with the earlier Avonlea points may be indicative of a connection between the two (Walde et al. 1995: 28; Linnamae et al. 1988: 168). Prairie Side-Notched points are predominantly associated with pottery from the Old Women's Phase (1150 – 700 years B.P.). The final precontact projectile point type on the Northern Plains is the Plains Side-Notched points, which are described as "generally small, with the notches placed high along the lateral margin giving the point a definite triangular outline" (Walker 1999: 27). Both Prairie and Plains Side-Notched points appear at the Amisk and Cut Arm sites within Wanuskewin Heritage Park.

3.3.1 Late Precontact Occupation at the Red Tail Site

At the Red Tail site, Layer 2 included both Besant and Avonlea material. Specifically, two Besant point bases were found in this layer during the excavation in 1988. Two Avonlea points and an endscraper were found during the 1982 shovel tests of the site and were presumed to have belonged to the same layer as the Besant points that were subsequently found (Ramsay 1993: 79).

As previously discussed, the completed archaeological analysis of the excavation at the Red Tail site focuses on the lower levels identified as definitive or potential McKean occupations. The upper portion of the excavation and the seven identified occupation levels in it were recorded; analysis and interpretation is currently underway (L. Williams, personal communication 2012).

Layers 3 through 7 did not produce any diagnostic artifacts, but it can be concluded, based on the Besant and Avonlea projectile points found in Layer 2 and the McKean projectile points starting in Layer 13, that those intermediate occupations could be associated with the Late Middle Precontact or beginning of the Late Precontact Period (Ramsay 1993: 79). Potentially, the current analysis of these occupations will result in a more thorough understanding of post-McKean habitation at the Red Tail site.

3.4 Conclusion

While very few definitive connections can be made between many cultural complexes, there is a consistent chronology of occupation of the Northern Plains. This chapter outlines the culture history of groups occupying the Northern Plains who would have experienced the climate and environmental changes outlined in this thesis. While not all complexes are represented at the Red Tail site, there is certainly representation of many groups within Wanuskewin Heritage Park as a whole.

Chapter 4: Methodology

4.1 Field Methodology

In July of 2007, five cores were taken from the Red Tail site using a Model 5400 Geoprobe mounted on the bed of a four-wheel drive Ford F350 pickup truck (Figure 4.1). Geoprobe cores are particularly useful because of their high level of stratigraphic integrity; this results from the direct push hammer system that is used in collecting them. The cores are removed from the ground in a cylindrical plastic tube, maintaining the original context of the sediment, which preserves depositional bands with minimal disturbance. Coring is often chosen as a method of subsurface investigation for paleoenvironmental research, even at archaeological sites, because it is faster, less expensive and less intrusive than traditional excavation or backhoe trenching. Coring also allows deeper sampling than would often be feasible with other methods of subsurface investigation.

The coring locations were chosen to avoid the previously excavated portions of the archaeological site, which were identified with the assistance of site excavator Dr. Ernest Walker. Because coring with this rig is most effective when the truck can be parked in a level area, the cores were concentrated to the south and west of the previous excavations, where topography and vegetation provided the most promising terrain (E. Robertson, personal communication 2013).

Figure 4.1. Geoprobe coring at the Red Tail site, July 2007. View to the Southeast. Behind the Geoprobe rig is a meander bend of the South Saskatchewan River. The aspen grove to the right denotes the ephemeral drainage adjacent to the site (Photo credit: L. Foley).

The clear plastic sample tubes and coring gear used for this project collected sediment columns measuring approximately 4 cm in diameter. Each core is taken in a number of sequential drive sections no more than 4' long. To minimize contamination between the drive sections, a rod and piston insert is used to seal the sample tube until the core reaches the terminal depth of the previous drive, then removed to allow collection of the next drive. When each drive section is retrieved, the bottom 10 cm of each sample remains lodged in the drive shoe, the bevel-edged cap that acts as a cutting edge into the borehole. Although removal of the sample from the drive shoe generally destroys stratigraphy of the sample, the samples are retained to offer some insight into the composition of the intervals between drives.

These five cores were frozen within several days of their recovery, and the two selected for analysis by this study were not thawed until they could be descriptively logged and subsampled for analysis. Freezing the cores prevents breakdown of organic components of potential buried soils, which are important in subsequent radiocarbon and organic carbon content analyses. Cores WNS-RT-03 and WNS-RT-05 were chosen for further evaluation based on their depth and integrity. Both cores reached a depth of more than six meters and did not encounter obstacles during their recovery, such as subsurface rocks, which can distort the structure of the sediment as it is driven into the sample tubes. WNS-RT-03 was taken from a location several meters to the south of the original Red Tail excavation, and WNS-RT-05 was taken several meters to the southwest of the excavation, placing the two cores about 4 m from one another (E. Robertson, personal communication 2013).

4.2 Laboratory Methodology

A major objective of the laboratory investigation of the core samples was to identify potential buried soils. While sediments can be defined broadly as inorganic or organic solids in particulate form, soils are formed through the physical and chemical transformation of sediments during times of landscape stability. This process is called pedogenesis. The key component of soil formation is the establishment and growth of vegetation. Other factors that also contribute to soil formation are climate, topography, parent material (i.e., the original sediment or rock) and length of time for which the landscape is stable. Climate and vegetation have significant influence on soil formation processes (Gerrard 2000: 45). Evidence of these soil formation processes can be used to infer information on climate and vegetation while the soil was developing.

4.2.1 Descriptive Logging of Cores

In the laboratory, the core drives of WNS-RT-03 and WNS-RT-05 were thawed and the plastic sample tubes were cut open, one drive at a time. The material inside the core was trimmed using a sharp knife to expose sediment undisturbed by friction with the interior of the tube during coring. This created a uniform profile to be examined. Photographs were taken of each drive section before logging began. Sediment layers present within the core were identified, measured and recorded from the top to bottom of each drive. Sediment layers were initially identified based on colour, soil and sediment structure, mottling and inclusions, and texture by feel, as per Birkeland's procedure (1999: 347-359).

Each sediment band identified within the drives was then more thoroughly examined and recorded. Attributes recorded while logging cores include: depth and morphology of upper and lower boundaries, colour (based on the Munsell Soil Color Charts 2000), texture (based on the Canadian System of Soil Classification 1998), soil and sediment structure, consistence, calcium carbonate content (estimated by effervescence when exposed to 5% hydrochloric acid in distilled water), mottling and inclusions.

Boundaries between layers were described based on distinctness (abrupt, clear, gradual or diffuse), but given the narrow diameter of the core, it was difficult to determine general topography (smooth, wavy, irregular or broken), which is the other attribute typically recorded for boundaries (Birkeland 1999: 356). Boundaries are formed when breaks or changes in deposition of sediments occurs, due to an interval of stability, a period of erosion or a major change in the deposition occurring. Boundaries are important in identifying potential buried soils, as depositional hiatuses offer the opportunity for landscape stability and pedogenesis to begin (Rapp and Hill 2006: 58). Additionally, soil formation involves the development of distinct horizons within soils, a process which creates additional boundaries within sediment columns.

Sediment and soil colours were described according to the Munsell Soil Color Chart. Sediment and soil colour variation is affected by a number of different factors, including parent material, mineral content, organic material and moisture content (Gerrard 2000: 39). For consistency, all colours were described using moist samples. Colour was particularly significant in identifying soil horizons in parts of the cores where possible buried soils were present, as the three mostly commonly identified horizons are typically characterized by colour differences. In particular, A-horizons (Figure 4.2) form immediately under surface vegetation, making them higher in organic material and darker in colour (Brady and Weil 2002: 122). B-horizons are formed by the accumulation of A-horizon material leaching downward through the soil and/or by pedogenic alteration of the parent material. C-horizons exhibit a lack of both colour development and pedogenic activity; these horizons are only slightly changed or modified from the parent materials from which soils form (Soil Classification Working Group 1998: 12). Another possibility indicated by colour is gleying. Gleying occurs when sediments are saturated with water for extended periods resulting in a bluish or greenish gray colours, for which there are specific pages of the Munsell Soil Color Chart.

Mottling can be defined as "spots or blotches of different color or shades of color interspersed with the dominant color" (Brady and Weil 2002: 925). Mottling is significant because it can indicate sediment or soil disturbance by a number of different factors. For example, rodents actively burrowing in the area cause bioturbation, which can result in portions of sediments being found outside of their original context. Obviously, this can complicate the identification and interpretation of sediment layers and soil horizons and is therefore important information to record during analysis. Mottling and inclusions were noted where apparent based on quantity, size and contrast, as per Birkeland's procedure (1999: 347-359).

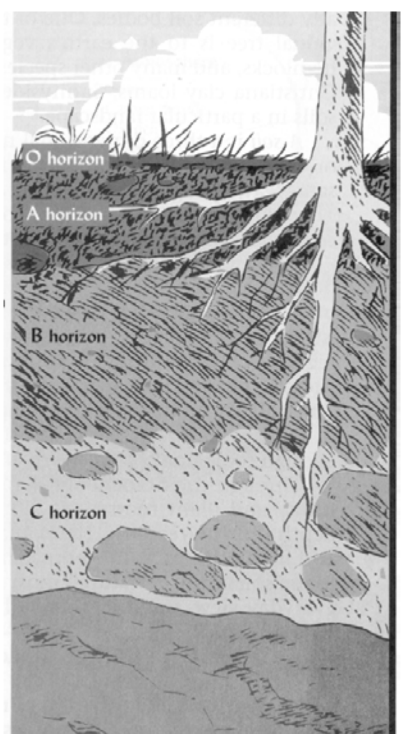


Figure 4.2. Soil profile diagram demonstrating horizonation (Brady and Weil 2002: 12).

Soil texture is the relative proportions of sand, silt and clay within in a given soil sample. Combinations of these particle size classes are described using eleven textural size classes (Gerrard 2000: 22). Sand is commonly defined as particles ranging in size from 0.05 mm to 2 mm and feels gritty to the touch. Silt particles are between 0.002 mm and 0.05 mm and lack the gritty feel of sand, but are not as sticky or plastic as clay particles. Clay particles are smaller than 0.002 mm and are easily malleable when moist (Brady and Weil 2002: 123-125). Soil textural classes are defined based on ratios of sand, silt and clay particles; this study employed the textural classes used in the Canadian System of Soil Classification, which are presented in Figure 4.3. Texture is considered one of the most important characteristics when examining sediment or soil horizons because this can indicate several things, including the energy of the geomorphic processes responsible for deposition (Brady and Weil 2002: 123; Courty et al. 1989: 17-18). The larger the particles within the soil or sediment the greater the energy needed to transport them, whereas soils or sediments made up of small particles can be transported by less energetic geomorphic processes. Very small particles, however, require a large amount of energy in order to initiate movement because of the cohesive bonds between clay particles, in particular.

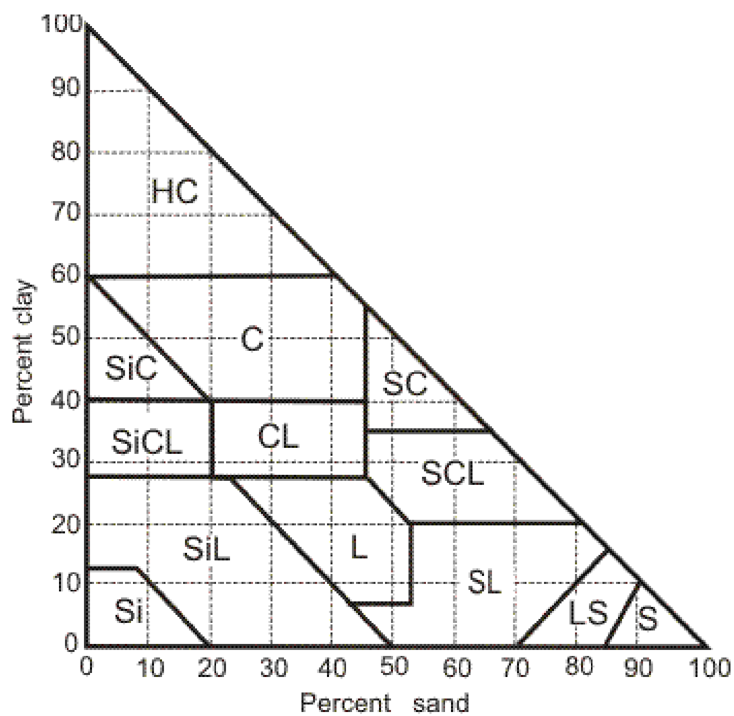


Figure 4.3. Soil Texture Classes Triangle. (The Canadian System of Soil Classification) Abbreviations: Heavy Clay (HC), Clay (C), Silty Clay (SiC), Silty Clay Loam (SiCL), Clay Loam (CL), Sandy Clay (SC), Silt Loam (SiL), Loam (L), Sandy Clay Loam (SCL), Sandy Loam (SL), Silt (Si), Loamy Sand (LS) and Sand (S). (Soil Classification Working Group 1998: 158).

Soil structure develops in situ due to changes within the sediment associated with pedogenesis; sediment structure, on the other hand, is a result of the process responsible for their deposition. Soil structure takes the form of peds, formed by particles becoming adhered to one another to form an aggregate. Peds are separated by the Canadian System of Soil Classification into four main categories: structureless, blocklike, platelike or prismlike (Soil Classification Working Group 1998:159). Identifying soil structure within the core is very difficult for a number of reasons. The narrow diameter of the core sample, as well as the process of core extraction, can negatively affect ability to identify peds within the core due to the small sample size and compression of the sediments during recovery. Buried soils in areas of frequent deposition, such as the Red Tail site, often are poorly developed, lacking peds because there was not sufficient time for them to form. Alternatively, sediment structure can be used to help inform on what geomorphic processes were responsible for their deposition. For example, fining upward sequences, or sequences of deposits whose particle size becomes gradually finer upwards through the core, may be indicative of the decreasing energy of sediment-bearing water in flooding events, something that would not be surprising to see at the Red Tail site.

Consistence, "a measure of the adherence of the soil particles to the fingers, the cohesion of soil particles to one another, and the resistance of the soil mass to deformation" (Birkeland 1999: 353), was recorded based on friability, stickiness and plasticity to give a secondary measure of clay content in the cores. Consistence reflects the resistance of the soil or sediment to stress or manipulation (Brady and Weil 2002:165). Friability of a soil is determined by breaking apart a dry sample using your fingers. Soil stickiness is tested by pressing a small amount of wet soil between your thumb and forefinger and then pulling your fingers apart. If the soil is very sticky, it sticks firmly to your fingers and stretches as you pull your fingers apart. Plasticity is determined by rolling the moist soil into a long, thin strip. The higher the plasticity of the soil, the longer the strip will become before breaking.

In order to identify the presence and relative abundance of carbonates in the horizons, a few drops of 1M HCl was added to a small amount of sample and the reaction was recorded based on a four-point scale ranging from very slightly effervescent to violently effervescent. There are two main forms of carbonates that occur in depositional settings like the Red Tail site. Primary carbonates are lithogenic, meaning that they are inherited from the parent material. Pedogenic carbonates, on the other hand, are composed of calcium carbonate that has been dissolved, translocated and re-precipitated in secondary locations as a result of soil formation (Gerrard 2000: 95, Jahn et al. 2006:

38). This solution and translocation occurs due to water passing through the sediments from various inputs (i.e., groundwater or precipitation) during the process of soil formation (Gerrard 2000: 95).

4.2.2 Particle Size Analysis Procedure

Once the cores had been logged, a portion of each soil or sediment layer was set out to air dry. The remaining sample was packaged, labeled and refrozen as a reserve for potential future sampling. The dried samples were then disaggregated using a mortar and pestle in order to break up any remaining soil structure, while being careful not to break down particles into smaller pieces. The samples were then sieved using a sequential stack of mesh sieves measuring 16.0, 11.2, 8.0, 5.6, 4.0, 2.8, 2.0, 1.4, and 1.0 mm. The weight of the sample retained in each sieve was recorded. The samples were then transferred into plastic bags and labeled as larger and smaller than 1 mm.

Subsamples of approximately 2 g were then taken from the <1-mm portion of the sample and transported to the University of Calgary for automated particle size analysis. The samples were processed using a Malvern Instruments Mastersizer 2000, a system that uses laser diffraction in order to measure distribution of particle sizes within a sample. The <1-mm portion of the sample was used because the maximum particle size that the Mastersizer can process is 2 mm and it can encounter operational difficulties when analyzing particles greater than 1 mm. Since the samples had already been disaggregated using a mortar and pestle, the first step was to pass the sample through riffling chutes in order to select a random, but representative, subsample weighing between 0.1 g to 2.0 g. This procedure avoids particle size bias that may result from subsampling off the top of a bagged or sieved sample, while also providing an optimal volume of subsample for analysis by the Mastersizer (D. Wilson, personal communication 2012).

Once the random samples were selected, they were placed in 50 ml beakers to which 2 ml of 30% hydrogen peroxide solution was added in order to remove any organic material. This process was repeated until any effervescent reaction ceased. If necessary, the samples were heated to 60ºC in order to speed up the elimination of organic material. Organic materials left in the sample can heavily impact the textural ratio of the sample because they often facilitate the formation of aggregated masses of particles (Gray et al. 2010). Next, 10 ml of distilled water was added to the beakers in order to dilute any remaining hydrogen peroxide. The samples were then placed in a 105ºC oven overnight to air dry. Once dry, the samples were soaked in 5 ml of 5% Calgon solution (sodium hexametaphosphate) and 5 ml of distilled water, once again overnight. This process breaks up aggregated masses of clay particles in particular (D. Wilson, personal communication 2012)

The samples were vortexed to suspend the particles in their fluid carrier, and then added to the Mastersizer 2000 unit. The Mastersizer uses an automated standard operating procedure in order to ensure consistent analysis of samples. The particles are passed through a focused laser beam based on the principle that the angle of the light diffracted by each particle is inversely proportional to the size of each particle (Malvern Instruments Ltd. 2005, 2013). Photosensitive detectors measure the diffracted light, resulting in data that are then converted to particle size distribution tables and graphs displayed by the unit. The data were transferred into Microsoft Excel and reanalyzed to provide percentage values for the particle size categories found in the Canadian System of Soil Classification: clay (<0.002 mm), silt (0.002 – 0.05 mm) and very fine to coarse sand (0.05 – 1.0 mm) (Soil Classification Working Group 1998: 157).

4.2.3 Carbon Content Analysis Procedure

Carbon content analysis was performed in the Department of Soil Science at the University of Saskatchewan using a LECO-SC632 Sulfur/Carbon Determinator. The samples used in this analysis were the remaining portion of the samples that had been prepared for particle size analysis. These samples had been air dried, broken down with a mortar and pestle, sieved to 1 mm and stored in plastic bags until carbon content analysis was conducted. Open, boat-shaped crucibles are used in this machine because the increased surface area provides more complete and efficient combustion, as well as enhanced carbon recovery from the sample (LECO 2012).

The procedure for carbon content analysis testing of organic carbon began with weighing standards of Sucrose and Soil 06 in order to ensure the auto-analyzer was correctly calibrated. Sucrose is used as a high-carbon-level standard, whereas Soil 06 ensures calibration of any low-carbon measurements. The organic carbon testing was conducted at a temperature of 813ºC. Once four of each of the standards were measured into a boat-shaped crucibles, the weights of each standard were input into the external PC that provides operational control. The standards were then each individually loaded into the Determinator's ceramic furnace tube using a long, hooked metal rod and analyzed according to the standard operating procedure, then removed and allowed to cool.

Once calibration was complete, approximately 0.15 – 0.2 g of each sediment sample was weighed into individual crucibles. Each sample was loaded into the auto-analyzer using the same procedure as for the standards. After inputting the sample number and weight of the sample into the spreadsheet on the PC, the analysis was started. Once complete, the crucible was removed from the auto-analyzer and then set aside to cool. The next sample in the sequence was then placed in the auto-analyzer and the process was repeated.

The standard used for total carbon analysis was calcium carbonate. A set of four standards was run, in the same way as the previous standards. The only changes in the procedure for total carbon are the selection of this particular test within the computer settings and the temperature used, which, for total carbon, is 1100ºC. Otherwise, the procedure above was repeated for the same sequence of samples using another 0.15 – 0.2 g of the dried, deaggregated and sieved sediment. In order to calculate inorganic carbon content of the samples, the organic carbon value was subtracted from the amount of total carbon present in each sample.

4.2.4 Stable Carbon Isotope Analysis Procedure

While the majority of the samples from the core were analyzed for stable carbon isotopes, it was not feasible to include them all due to the expense. The samples that were included were selected from parts of the core that illustrated periods of stability and soil development in the form of A-horizon formation. In order to contrast with the A-horizon samples, the C-horizon below each A-horizon sample was also analyzed. Approximately 1 g of each dried, disaggregated sample were weighed into a tared 100 ml beaker using a balance that weighs to 0.0001 g. Carbonates were removed from the sample by adding 25 ml of 10% HCl to each beaker. These are likely authigenic carbonates that formed after interment of the buried A-horizons, rather than the previously mentioned pedogenic variety, and they are therefore not useful for analysis. The samples were left overnight to ensure completion of the effervescent reaction.

The samples were rinsed of the acid using a disposable Thermo Scientific Nalgene funnel lined with 0.45 μm filter paper and coupled to a vacuum flask. The samples were transferred from the beaker into the funnel and rinsed three times with approximately 100 ml of distilled water. Once complete, the filter papers, now carrying cleaned sediment, were removed from the funnels, transferred to watch glasses and placed in a drying oven at approximately 80ºC overnight. Once completely dry, the samples were scraped from the filter onto weighing paper and were once again weighed. The samples were then folded up within the weighing paper to create small packages for shipment to the Isotope Science Laboratory in the Department of Physics and Astronomy at the University of Calgary.

In the Isotope Science Laboratory, approximately 10-mg subsamples were weighed into tin cups suitable for transfer into a Finnigan Mat Delta+XL mass spectrometer interfaced with a

Costech 4010 elemental analyzer. Each subsample was sequentially dropped by a Zero Blank auto sampler into the elemental analyzer. The entrance point for samples is a quartz tube combustion column, which is maintained at 1020 °C in order for the carbon in the samples to combust, forming CO_2 as soon as they enter the analyzer. The CO_2 is then passed through a gas chromatographic separation column before entering the mass spectrometer. There are four stages inside the mass spectrometer: ionization, acceleration, deflection and detection. Once ionized to creative positive ions, the particles are accelerated to ensure equal kinetic energy. The particles are then deflected by a magnetic field based on their mass/charge ratio. A detector at the end of the system records the stable isotope content (Gross 2011).

4.2.5 Phytolith Analysis Procedure

Samples for phytolith analysis were selected based on probable identification of buried A-horizons, since these should be layers in which deposition of tissue from dead plant concentrated phytoliths during soil formation. Immediately underlying C-horizons were included as comparative samples. Again, this procedure used material from the samples, which had already been air-dried, gently disaggregated using a mortar and pestle and sieved through a 1-mm mesh screen. Five-gram samples were weighed into 100 ml beakers and treated with 5 ml of 1M HCl in order to remove the carbonates in the sample; this step breaks up any aggregates of sediment cemented by carbonates and frees any phytoliths trapped in such aggregates. Additional HCl was added to some highly effervescent samples to ensure a complete reaction. They were left for an hour or two to ensure complete removal of the carbonates.

Once this reaction was complete, the samples were transferred to disposable plastic 50 ml centrifuge tubes. The centrifuge tubes were topped up with distilled water and then centrifuged for five minutes at 3 500 RPM. The supernatant was decanted off into a large beaker leaving a pellet of sediment, including phytoliths, in the bottom of the tube. The process was repeated three times using distilled water in order to rinse off any remaining HCl. Five milliliters of 30% hydrogen peroxide was then added to each sample in order to remove any organic content that may have been aggregating sediment particles in which phytoliths could be caught up. The samples were agitated and then left overnight for the reaction to go to completion.

The following day, the samples were rinsed using the same process of filling the tube with distilled water, centrifuging and then decanting off the supernatant. This process was repeated three times. The samples were then returned to 800 ml beakers, making sure to rinse all the particles into the beakers using distilled water. Twenty-five ml of 5% Calgon solution was then added to each beaker, followed by enough distilled water to fill the beakers to a height of 8 cm. The samples were then thoroughly agitated using a stir stick. In order to remove clay-sized particles, the samples were allowed to settle for one hour. Based on the principles of Stokes' Law, the sand and silt-sized particles, as well as the phytoliths, settle to the bottom in that time frame, leaving the clay-sized particles suspended in the water and easily removed using a 60 ml syringe. Once the distilled water containing the clay-sized particles was removed, the beakers were refilled with clean distilled water to the 8-cm mark and once again thoroughly agitated. This process of agitating, settling and syringing was repeated until the distilled water was clear after the one-hour settling cycle. The samples were also agitated using an ultrasonic cleaner on the second and third settling cycles to ensure any remaining clusters of sediment particles and any associated phytoliths were entirely broken up and thoroughly mixed with the water. The number of settling cycles required to obtain a clear sample was also recorded. Once the water in the samples was clear after a one-hour settling cycle, it was removed and the remaining sand and silt-sized particles left in the bottom of the beaker were dried at about 80ºC in the drying oven overnight.

Using a weighing scale that measures to 0.0001 g, approximately 0.5000g of dried sample was measured into a 15-ml centrifuge tube. The remaining dried sample was transferred into a 50-ml centrifuge tube for storage. Sodium polytungstate (SPT) powder was dissolved in distilled water to create a heavy liquid with the density of 2.3 g/ml. Five milliliters of this heavy liquid was added to each 0.5000g sample in order to separate out the phytoliths from the sample. Because their density is less than 2.3 g/ml, the phytoliths float to the top of the heavy liquid when spun in the centrifuge, whereas the heavier sand and silt mineral particles sink to the bottom. The samples were centrifuged at 3 000 RPM for 10 minutes and then the heavy liquid bearing the floating phytoliths was poured off into a second 15-ml tube. Distilled water was added to the new tubes in order to decrease the density of the heavy liquid, allowing the phytoliths to then sink to the bottom of the tube when centrifuged again at 3 500 RPM for 5 minutes. The diluted heavy liquid was then poured off, and the phytoliths that had collected at the bottom of the tube were washed of any remaining heavy liquid residues in three rinses of distilled water, with 5 minutes of centrifugation at 3 500 RPM between each wash. Once rinsed, the samples were allowed to dry at about 80ºC in the drying oven overnight.

Lycopodium spores were added to the sample as a control, allowing calculation of an estimate of absolute phytolith numbers and densities in each sample. One *Lycopodium* spore tablet, containing 18 583 spores (University of Lund Batch No. 483216), was added to each phytolith sample

(Berglund and Persson 2004). Ten milliliters of 1 M HCl was added to the centrifuge tube in order to dissolve the tablet's binding substance. Once the reaction was complete and the tablets were completely dissolved, the tubes were topped up to 15 ml and centrifuged at 3 500 RPM for five minutes. The HCl was decanted, and then the samples were rinsed three times using distilled water and the aforementioned procedure. The samples were once again dried at about 80ºC in the drying oven overnight.

The phytolith samples were mounted onto labeled glass 75 mm x 25 mm x 1 mm microscope slides using bamboo skewers to transfer them to the slides and mix them into the mounting medium, which was natural filtered Canada balsam. The slides were secured using 24 mm x 40 mm cover slips. Canada balsam is a transparent, viscous substance that does not immediately set, allowing rotation of the phytoliths under magnification; this is helpful in identification. Once transferred to the slides, the phytolith samples were covered with a slide cover and gently compressed to remove any bubbles from the Canada balsam. The slides were then examined in order to identify and count phytoliths and *Lycopodium* spores.

The slides were examined using an Olympus CX41 microscope with options for 100x, 200x, 400x and 600x magnification. The majority of the scanning was conducted using 400x magnification, although higher magnification was sometimes useful for examining individual particles. Phytoliths were described based on basic features of shape, size and comparison to images of known morphotypes (e.g., Figure 2.9). Although Pearsall recommends phytolith counts of 200 for better statistical reliability (2000: 450), the phytolith density of the samples in this research were too low to reach this goal. Instead, where possible, counting continued until 100 short-cell phytoliths were identified, or until the entire slide was scanned. Presence of non-short-cell phytoliths was recorded where possible, but particular attention was paid to counting and categorizing short-cell phytoliths. In samples where a particularly low number of phytoliths was recorded, second slides were mounted and scanned in order to ensure the low count was not due to mounting error. Along with both short-cell and non-short-cell phytoliths, *Lycopodium* spores were counted in order to determine absolute numbers of phytoliths in the samples.

A selection of photographs were taken using a Zeiss West Germany photomicroscope coupled with a Moticam 2300 microscope camera. The photographs were taken at 400x magnification of several individual phytoliths in order to illustrate the types found in the samples. The images were captured and a scale was added using Motic Images Plus 2.0ML digital camera microscope software. The microscope used for conducting the phytolith counts was not ideal for photography; therefore, only a small selection of images were taken using this other microscope, to which access was limited.

4.2.6 Radiocarbon Dating

There were two samples selected for radiocarbon dating based on their location within WNS-RT-05, the core that was selected for more intensive analysis. This core was selected for more intensive analysis based on the more complete data set due to the presence of drive shoe samples. The samples for radiocarbon dating were selected from samples determined to be probable A-horizons. The material dated in both samples was organic matter.

The samples were sent to Beta Analytic Radiocarbon Dating Laboratory located in Miami, Florida for standard AMS radiocarbon dating. Pretreatment of the samples conducted at the laboratory included sieving the sediment to <180 microns to remove any roots or macrofossils followed by an acid wash to remove carbonates. The dates were calibrated using the newest (2009) calibration database (Appendix C).

Chapter 5: Results

5.1 Introduction

This chapter presents the results from the descriptive logging, particle size analysis, carbon content analysis, stable carbon isotope analysis, phytolith analysis and radiocarbon dating of the cores from the Red Tail site. Interpretation of these results, including correlation with the previously excavated archaeological material from the site, can be found in the next chapter.

5.2 Descriptive Logging, Particle Size Analysis and Carbon Content Analysis Results

The results of the descriptive logging of the cores WNS-RT-03 and WNS-RT-05 are summarized and presented in the form of stratigraphic columns (Figure 5.1 and Figure 5.2). A stratigraphic column is a graphic representation of the sequence of soils and sediments recovered within an exposure or core. Each bar on the stratigraphic column reflects the segments that the cores were initially divided into during descriptive logging, which were determined based on colour, texture and sometimes sedimentary structure. While structure of the sediments was generally massive, there were rare occasions that sedimentary structures such as laminae were preserved and distinguishable within the cores. The vertical position of the bars is reflective of the depth of the soil or sediment below surface and their vertical thickness indicates the thickness of the identified strata.

During the collection of the cores using the Geoprobe rig, some compression or expansion of the cores is expected. This compression or expansion is corrected using the depth measurement recorded off of the coring rig. Measurements of the drive were taken in the field on the Geoprobe rig and then again in the laboratory using a measuring tape when the cores were dismantled. To calculate the correct measurement of each segment, the laboratory measurement of the segment was divided by the total depth of the core drive as measured in the laboratory and then multiplied by total measurement of the core drive as measured on the rig. This is illustrated in the following equation:

$$\textit{Corrected Segment Thickness} = \left(\frac{\textit{Field Measurement of Drive}}{\textit{Lab Measurement of Drive}}\right) \times \textit{Lab Measurement of Segment}$$

The horizontal width of each bar represents the texture of the soil or sediment. Results from the initial estimates of texture using hand testing were used in the stratigraphic columns. Results from the automated particle size analysis can be found in Appendix 2. While the automated particle size analysis is valuable, it was determined that the data underrepresented clay in the samples, and therefore the hand textures were selected for use in the stratigraphic columns. The sediments and soils were classified using the Canadian Soil Classification System; the texture classes identified within the core include: Clay (C), Silty Clay (SiC), Silty Clay Loam (SiCL), Clay Loam (CL), Sandy Clay (SC), Silt Loam (SiL), Loam (L), Sandy Clay Loam (SCL), Sandy Loam (SL), Silt (Si), Loamy Sand (LS) and Sand (S) (Soil Classification Working Group 1998: 158). The texture classes present in the core were combined and represented using a numerical scale of 1 to 5 for readability on the stratigraphic column. This textural scale can be found in the legend on the stratigraphic column.

Due to the fact that the automated particle size analyzer was only for use on particles smaller than 1 mm, all samples were sieved to remove any particles larger than 1 mm prior to this analysis taking place. The amount of sample in both the smaller and larger particle size classes was weighed, the results of which were used to calculate the amount of gravel present in the soil or sediment. Results are illustrated in the stratigraphic column by pattern fills for soil or sediment samples containing percentages of gravel greater than 20% by weight of the total sample. Samples with values greater than 20% are described as gravelly, whereas samples greater than 50% are described as very gravelly according to *The Canada Soil Information System: Manual for Describing Soils in the Field* (1982: 69). None of the samples from either WNS-RT-03 or WNS-RT-05 could be described as very gravelly.

Samples showing horizontal laminae are also highlighted on the stratigraphic column using a pattern fill. These laminae are a phenomenon produced by periodic deposition that results in a series of thin layers measuring 1 cm or less in thickness; they are visually distinguishable due to difference in colour, texture or other features that reflect cyclic variability in the source and/or energy of the depositional process that created them. Their geomorphic and interpretive significance will be discussed further in Chapter 6.

The drive shoe samples of WNS-RT-03 were not analyzed, due to their loss during a transfer between storage facilities; therefore they are not represented on the stratigraphic column in Figure 5.1. Tabular versions of the detailed descriptive core logs on which the stratigraphic columns are based can be found in Appendix 1. Figures 5.3a-g are photographs taken of the drives from the core selected for more intensive analysis, WNS-RT-05, when they were first opened and cleaning in the laboratory.

The organic carbon content of samples can assist in identifying potential buried A-horizons in the core. Figure 5.2 illustrates the results of organic and inorganic carbon content analysis of samples from the core WNS-RT-05. High carbon values generally correspond with samples identified as probable buried A-horizons in the stratigraphic column found in Figure 5.2.

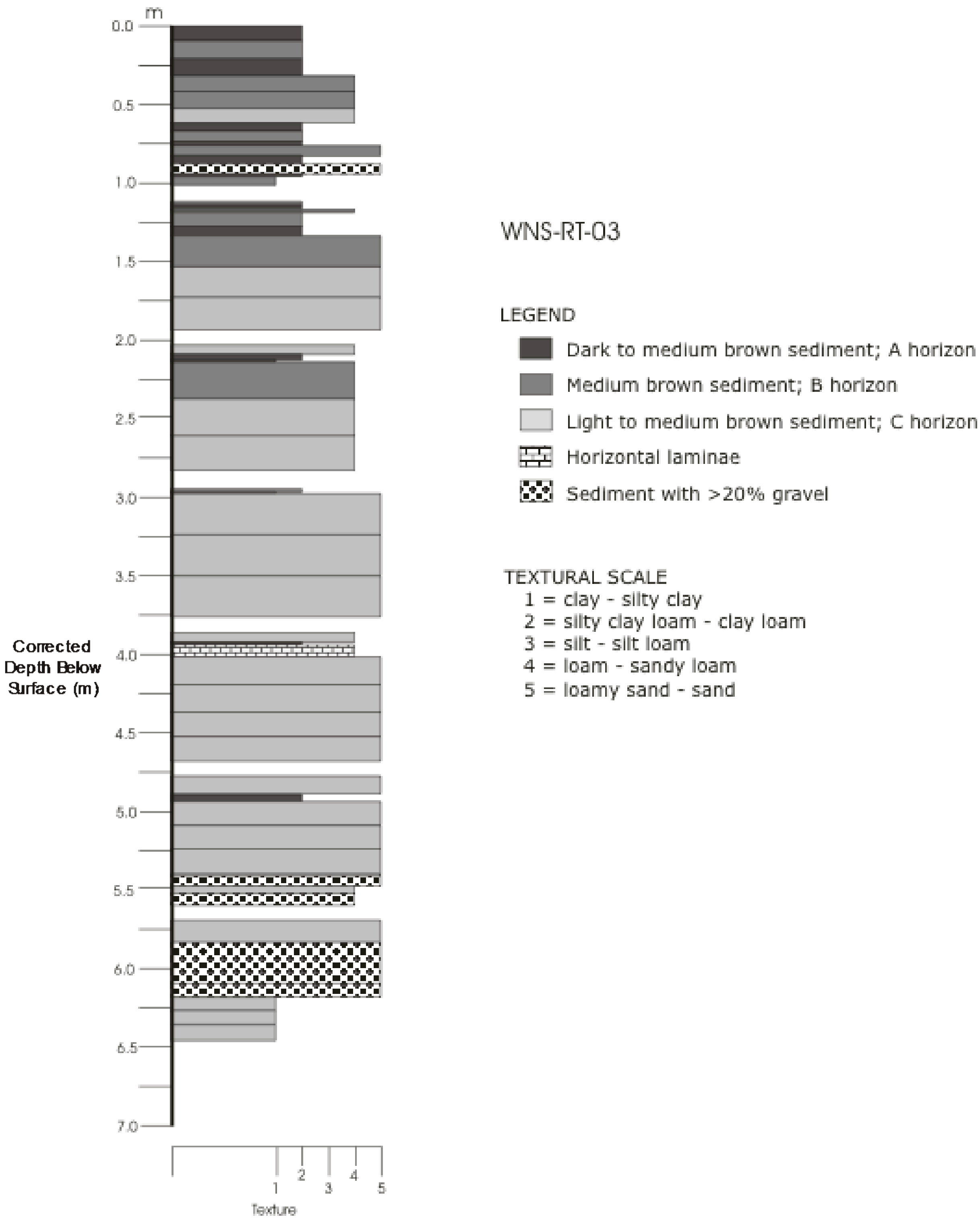


Figure 5.1. Stratigraphic column of WNS-RT-03.

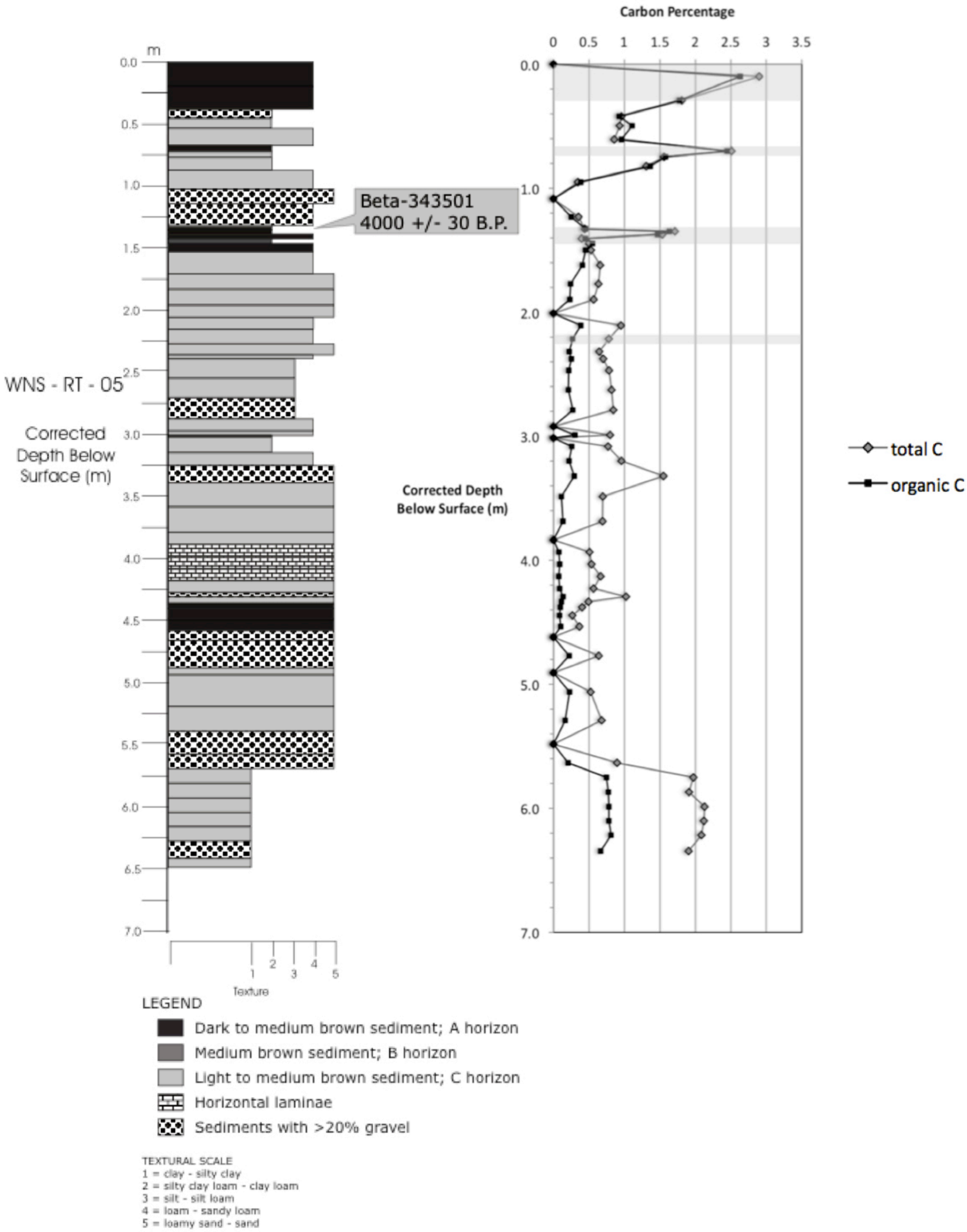


Figure 5.2. Stratigraphic column of WNS-RT-05. Organic and inorganic carbon content of samples from WNS-RT-05. Probable buried A-horizons are identified by shaded areas.

Figure 5.3a. Photograph of WNS-RT-05 Drive 1.

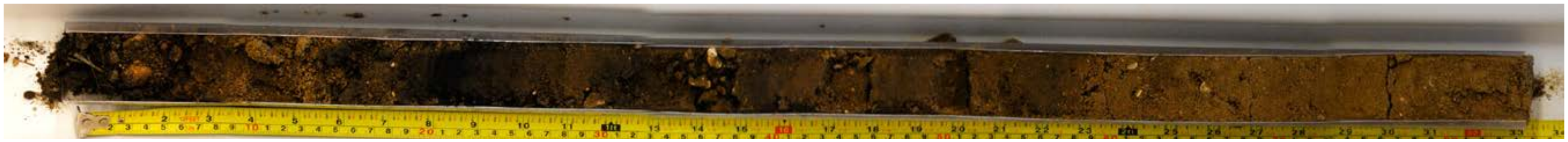


Figure 5.3b. Photograph of WNS-RT-05 Drive 2.

Figure 5.3c. Photograph of WNS-RT-05 Drive 3.

Figure 5.3d. Photograph of WNS-RT-05 Drive 4.

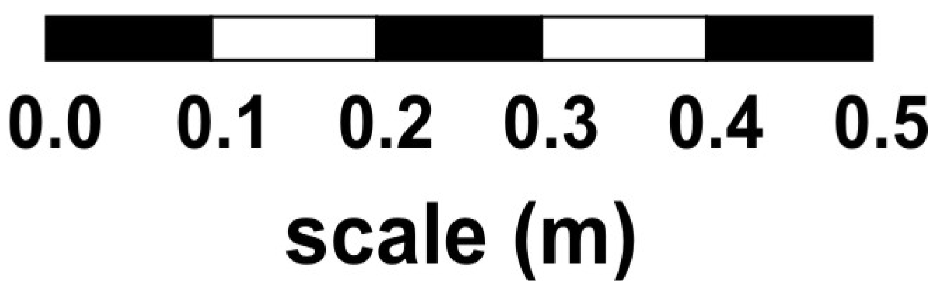
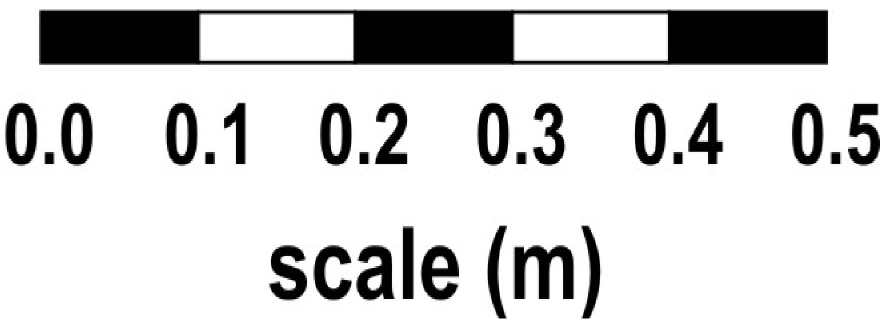


Figure 5.3e. Photograph of WNS-RT-05 Drive 5.

Figure 5.3f. Photograph of WNS-RT-05 Drive 6.

Figure 5.3g. Photograph of WNS-RT-05 Drive 7.



5.3 Radiocarbon Dating Results

The first sample produced a radiocarbon date of 4000 +/- 30 years B.P. (Beta-343501). This date, along with the depth below surface from which the sample was taken, correlates well with the radiocarbon dates and diagnostic artifacts from the previously completed archaeological excavation. This correlation and its significance will be discussed further in the next chapter.

Unfortunately, the second sample (Beta-343502) produced a date that does not correlate with its stratigraphic position within the core. This sample has thus been identified as slop scraped from the sides of the core hole as this drive was lowered to the depth at which the previous drive end; for this reason, this date has been disregarded. Despite the use of methods designed to prevent the collection of sediment scraped from the sides of the core hole, it can be pushed to the bottom of the hole and is collected when the piston-and-rod array is released to unseal the sample tube and start collecting the new drive. During the descriptive logging of the core, any material determined to be slop is removed, but in this case the material was far enough down in the drive that it was mistakenly assumed to be actual sample rather than slop. Associated samples have also been removed from the stratigraphic column, stable isotope results and phytolith results.

Table 5.1. Radiocarbon dates for soil/sediment organic matter from the Red Tail site.

Sample Number	**Beta Sample ID Number**	**Corrected Depth Below Surface**	**Conventional Radiocarbon Age**	**$\delta^{13}C$**	**2 Sigma Calibration**
WNS-RT-05-02 20-22cm	343501	1.34 – 1.36 m	4000 +/- 30 B.P.	-24.3 ‰	4530 to 4420 Cal B.P.
WNS-RT-05-05 12-17cm	343502	3.98 – 4.02 m	2410 +/- 30 B.P.	-23.0 ‰	2680 to 2640 Cal B.P./ 2610 to 2600 Cal B.P./2490 to 2350 Cal B.P.

5.4 Stable Isotope Analysis Results

The results of the stable isotope analysis are presented in Table 5.2 and also graphically in Figure 5.4. The table includes corrected depths of the samples below surface, the carbon percentage of the sample used for stable isotope analysis, the $\delta^{13}C$ result, and the percentage of C_3 plants responsible for the deposition of the soil organic matter. Fields also included in the table are colour and soil horizon, in order to identify the possible A-horizons. The percentage of C_3 vegetation that makes up past plant communities was determined using the following conversion formula:

$$\% \, C3 \; Plants \; = \frac{\delta^{13}C_{(C3+C4)} - \delta^{13}C_{(C4)}}{\delta^{13}C_{(C3)} - \delta^{13}C_{(C4)}} \times 100$$

where $\delta^{13}C_{(C3 + C4)}$ represents the stable isotope result value, $\delta^{13}C_{(C3)}$ equals the average value produced by C_3 plants (-27‰), and $\delta^{13}C_{(C4)}$ equals the average value produced by C_4 plants (-13‰). This equation was used by Landi et al. (2003a: 411) to determine percentages of C_3 vegetation in modern soil samples from areas of grassland-to-forest transition across Saskatchewan. Landi et al.'s study area is similar both geographically and ecologically to the study area of the present research, so one can assume the equation is also suitable for determining percentages of C_3 vegetation of buried soils at the Red Tail site.

Table 5.2. $\delta^{13}C$ values for sediment samples from WNS-RT-05.

Sample Number	Drive Number	Uncorrected Top Depth Below Surface (m)	Uncorrected Bottom Depth Below Surface (m)	Corrected Top Depth Below Surface (m)	Corrected Bottom Depth Below Surface (m)	Munsell Colour (damp)	Soil Horizon	Delta 13C Result (C3+C4)	%C	C3 (‰)	C4 (‰)	**% C3 plants**
0-33cm U	1	0.00	0.17	0.00	0.20	10YR2/1 black	A	-25.2	3.0	-27	-13	**87.14**
0-33cm L	1	0.17	0.33	0.20	0.38	10YR2/1 black	A	-24.2	2.0	-27	-13	**80.07**
33-39cm	1	0.33	0.39	0.38	0.45	10YR3/2 very dark greyish brown	C	-23.7	0.9	-27	-13	**76.64**
39-46cm	1	0.39	0.46	0.45	0.54	2.5Y3/2 very dark greyish brown	C	-24.1	0.8	-27	-13	**79.14**
46-58cm	1	0.46	0.58	0.54	0.68	2.5Y3/2 very dark greyish brown	C	-23.3	0.9	-27	-13	**73.43**
58-62cm	1	0.58	0.62	0.68	0.72	10YR2/1 black	A	-25.1	2.8	-27	-13	**86.43**
62-66cm	1	0.62	0.66	0.72	0.77	2.5Y3/2 very dark greyish brown	C	-24.1	2.4	-27	-13	**79.57**
66-75cm	1	0.66	0.75	0.77	0.87	2.5Y3/2 very dark greyish brown	C	-24.0	1.5	-27	-13	**78.29**
75-88cm	1	0.75	0.88	0.87	1.03	2.5Y4/2 dark greyish brown	C	-23.8	0.4	-27	-13	**76.86**
0-18cm	2	0.98	1.16	1.14	1.32	2.5Y4/2 dark greyish brown	C	-24.2	0.1	-27	-13	**79.71**
18-20cm	2	1.16	1.18	1.32	1.34	2.5Y3/2 very dark greyish brown	C	-23.6	0.4	-27	-13	**75.93**
20-22cm	2	1.18	1.20	1.34	1.36	10YR2/1 black	A	-24.8	2.0	-27	-13	**84.43**
22-25cm	2	1.20	1.23	1.36	1.39	2.5Y3/2 very dark greyish brown	A	-23.4	0.8	-27	-13	**74.07**
25-29cm	2	1.23	1.27	1.39	1.42	2.5Y4/2 dark greyish brown	AB	-23.0	0.3	-27	-13	**71.29**
29-33cm	2	1.27	1.31	1.42	1.46	10YR4/2 dark greyish brown	A	-22.8	0.5	-27	-13	**70.29**
33-40cm	2	1.31	1.38	1.46	1.53	2.5Y4/2 dark greyish brown	A	-23.5	0.4	-27	-13	**74.93**
40-58cm	2	1.38	1.56	1.53	1.71	2.5Y4/2 dark greyish brown	C	-23.4	0.3	-27	-13	**73.93**
10-22cm	3	2.02	2.14	2.16	2.27	2.5Y4/4 olive brown	C	-23.6	0.2	-27	-13	**75.86**
31-34cm	3	2.23	2.26	2.36	2.39	2.5Y4/4 olive brown	C	-23.7	0.2	-27	-13	**76.57**
5-18cm	4	2.90	3.03	3.02	3.15	2.5Y4/2 dark greyish brown	C	-24.7	0.1	-27	-13	**83.86**
29-43cm	4	3.14	3.28	3.25	3.39	2.5Y4/3 olive brown	C	-24.9	0.1	-27	-13	**85.29**
65-69cm	5	4.44	4.48	4.42	4.45	10YR4/4 dark yellowish brown	C	-26.9	0.1	-27	-13	**99.57**
75-80cm	5	4.54	4.59	4.50	4.54	10YR4/4 dark yellowish brown	C	-27.0	0.0	-27	-13	**100**

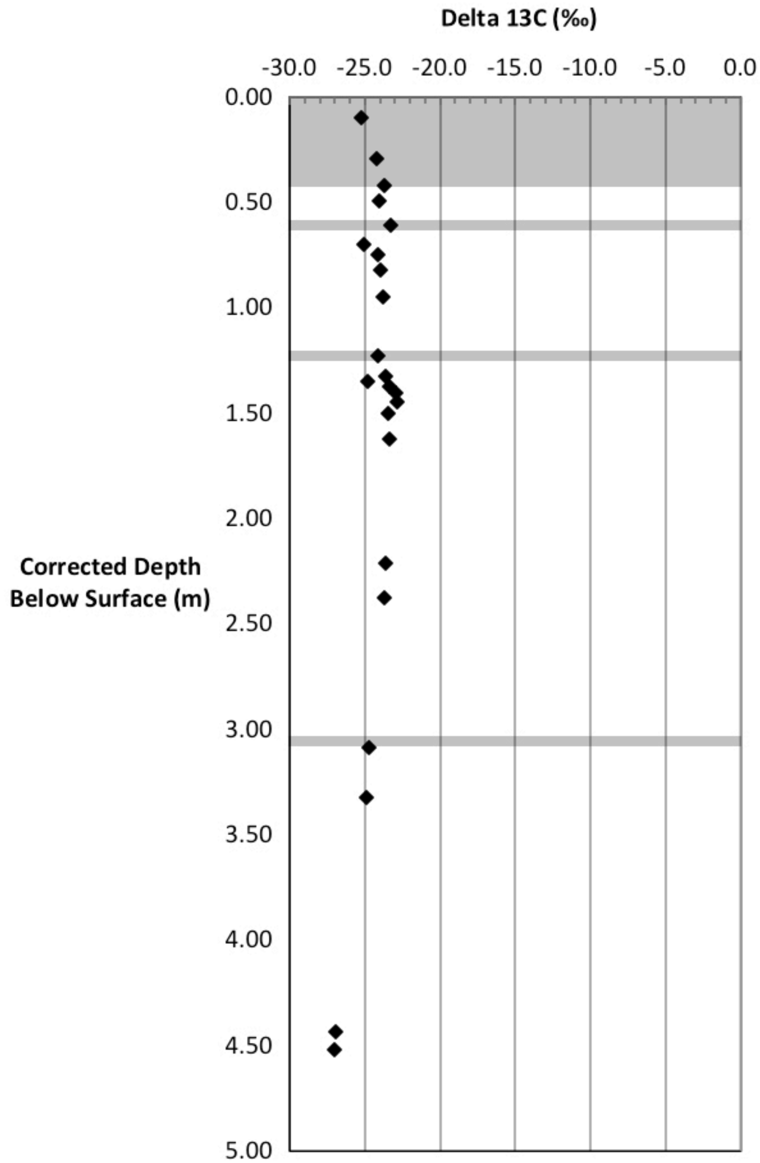


Figure 5.4. Stable carbon isotope results from WNS-RT-05.

5.5 Phytolith Analysis Results

Results of the phytolith analysis of the WNS-RT-05 core can be found in tabular form in Appendix 4. These tables present the data for raw counts of phytoliths found in the samples (Table A4.1), the calculated percentages of the observed phytolith morphotypes (Table A4.2) and the corrected absolute counts of the observed phytolith morphotypes based on the ratio of phytoliths to *Lycopodium* spore numbers (Table A4.3). Figure 5.5 includes photographs of several examples of phytoliths found within the samples, as well as a *Lycopodium* spore. The raw counts were conducted until a total of 200 phytoliths (all forms) were identified or until the entire slide had been scanned. Very few samples resulted in counts of 200; it was more common for the entirety of the slide to be scanned before that count was reached. In a few cases where identification as a probable buried A-horizon suggested that high raw counts should be observed, phytolith numbers were considerably lower than anticipated. In these instances, a second slide was mounted from the same processed sample, rescanned and recounted. In these cases, only the higher values are included in the tables and graphs of the results.

The phytoliths are broken down into the eight morphotype classes identified by Fredlund and Tieszen (1994: 324-327). A known quantity of *Lycopodium* spores (in this case, a tablet composed of 18 583 spores held together by a soluble binder) was added to the samples during the phytolith extraction process in order to later calculate corrected counts of phytoliths using the following equation (University of Lund Batch No. 483216; Berglund and Thomas 2004):

$$\textit{Corrected Count of Phytoliths} = \left(\frac{\textit{Total Lycopodium Spores}}{\textit{Lycopodium Spores Counted}} \right) \times M$$

where M equals the raw count of the phytolith morphotype being calculated.

Calculating corrected counts of phytoliths results in absolute numbers per weight of soil sample that was processed for phytoliths. In this case, approximately 0.5000 g of each sample was processed for phytoliths. The corrected count for each sample indicates the density of phytoliths in the sampled sediment. Unlike a relative measure, such as morphotype percentages, absolute phytolith count for a standardized mass of sediment sample makes it possible to compare phytolith concentrations between different samples, allowing these samples to be related different types of soil horizons or to densely versus sparsely vegetated environments.

Figures 5.7 and 5.8 present the relative percentages of the eight short-cell phytolith morphotypes, representing the frequency of different short-cell phytoliths in each sample relative to one another. Figures 5.9 and 5.10 present the corrected counts of the short-cell phytolith morphotypes, representing the absolute number of each phytolith morphotype from the 0.5000 g sample. The phytolith data are graphed against the depth below surface of the sampled sediment in order to allow correlation with the previously presented stratigraphic column.

Figure 5.11 illustrates the relative percentages of Pooid phytoliths (typically C_3 grasses) versus Panicoid and Chloridoid phytoliths (typical of C_4 grasses). High percentages of the morphotypes A (keeled), B (conical), C (pyramidal), D (crenate) and F (*stipa*-type) are indicative of Pooid-dominated grass communities, while high percentages of types E (saddle), G (simple lobate), and H (panicoid-type) demonstrate dominance by Panicoid and Chloridoid species.

Figure 5.12 shows the ratio of short-cell phytoliths identified in WNS-RT-05 to the non-short-cell forms also recorded. A higher number of non-short-cell phytoliths (i.e., a lower value for this ratio) may be indicative of increased non-grass vegetation such as trees or shrubs. While the focus of this study remains on the identification and interpretation of the short-cell phytoliths found within the samples, the data presented in Figure 5.12 offers some potential to look at the balance of grass and non-grass vegetation.

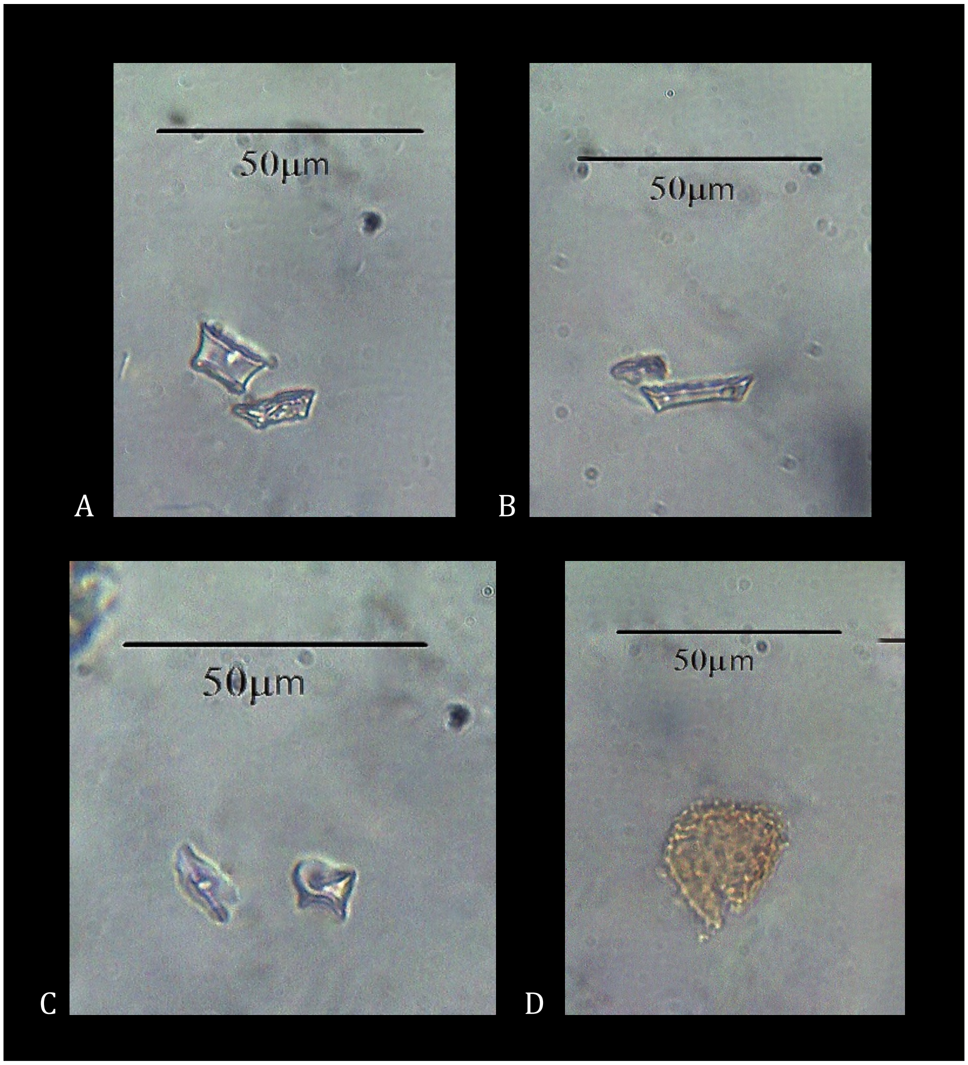


Figure 5.5. Examples of phytoliths found in WNS-RT-05. A. Morphotype F: *Stipa*-type; B. Morphotype D: Crenate; C. Morphotype E: Saddle; D. *Lycopodium* Spore.

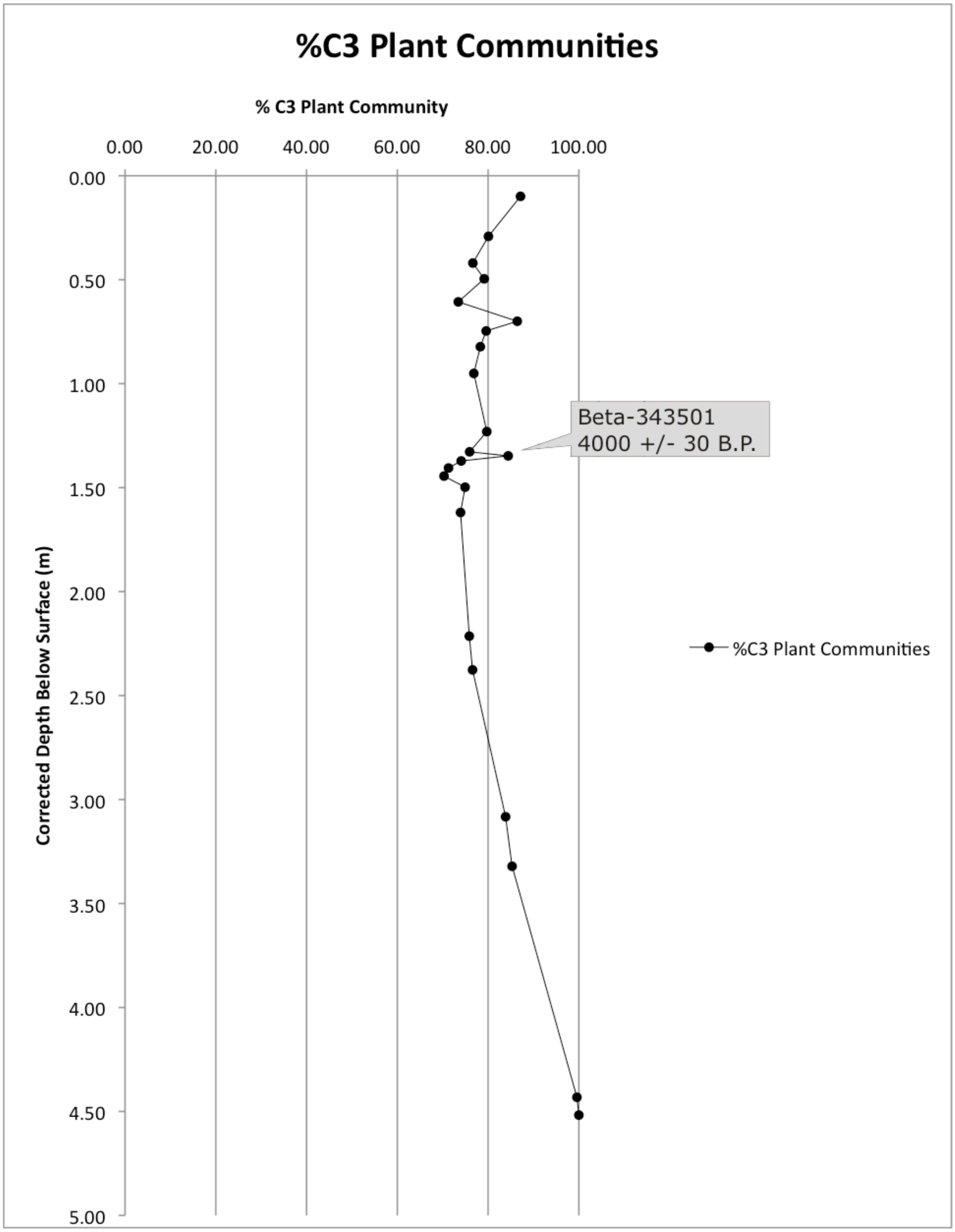


Figure 5.6. Percentage of plant community composed of C_3 vegetation in WNS-RT-05, based on stable isotope analysis results and conversion equation found in section 5.2 Stable Isotope Analysis Results.

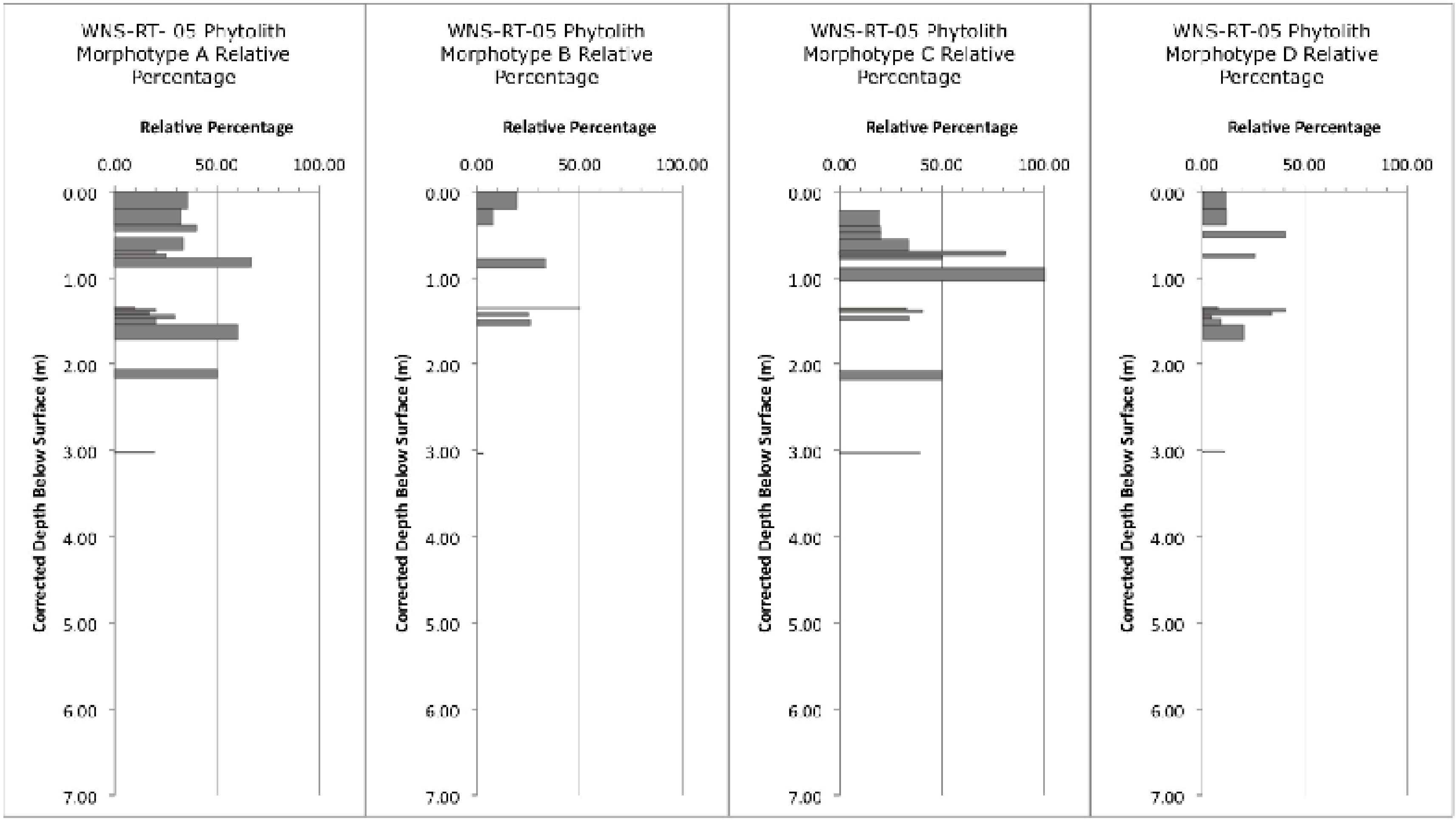


Figure 5.7. Relative percentage of short-cell phytolith morphotypes A, B, C and D in samples from WNS-RT-05. The height of each bar represents the thickness of the segment of sediment and its depth below surface.

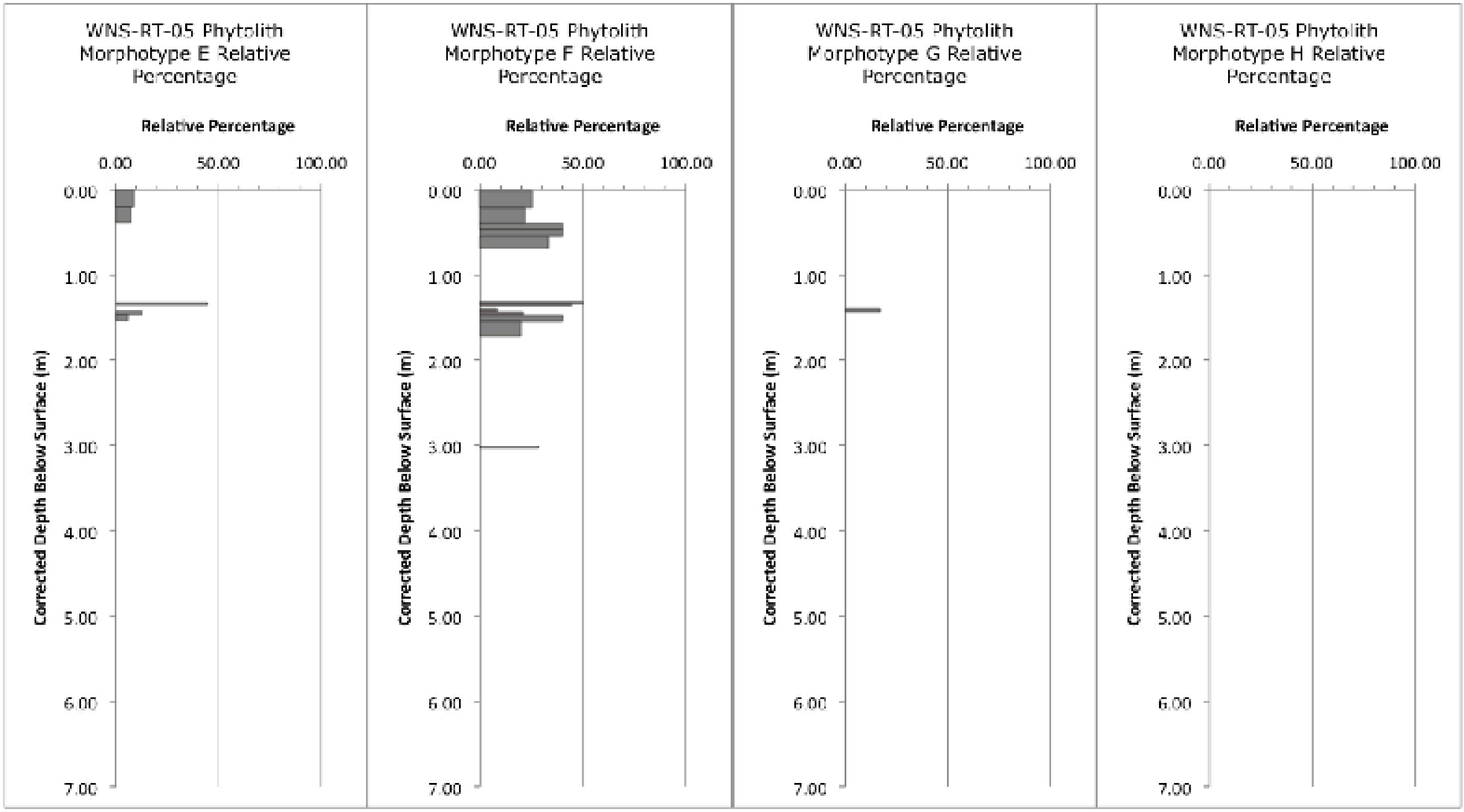


Figure 5.8. Relative percentage of short-cell phytolith morphotypes E, F, G and H in samples from WNS-RT-05. The height of each bar represents the thickness of the segment of sediment and its depth below surface.

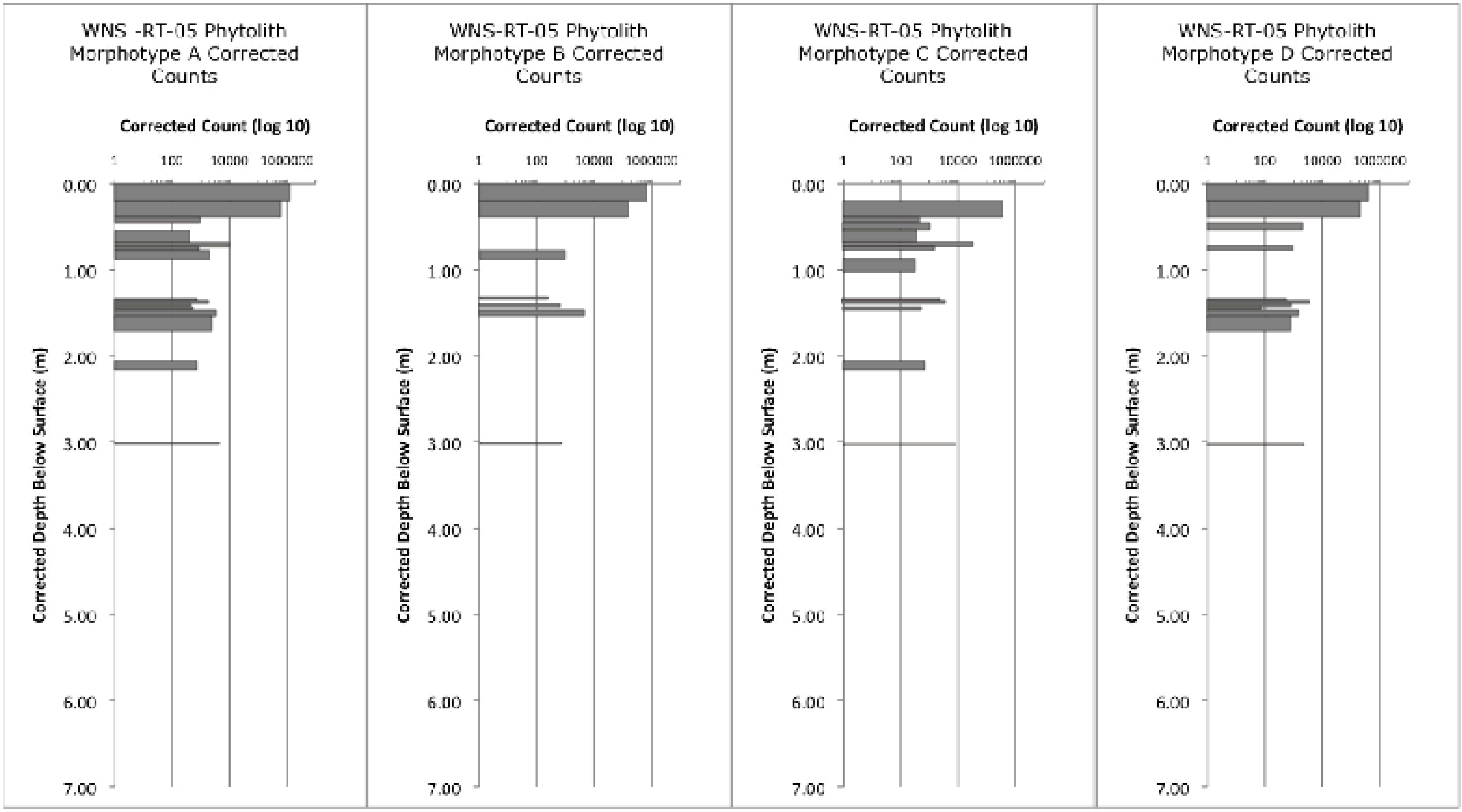


Figure 5.9. Corrected counts of short-cell phytolith morphotypes A, B, C and D in samples from WNS-RT-05. The height of each bar represents the thickness of the segment of sediment and its depth below surface.

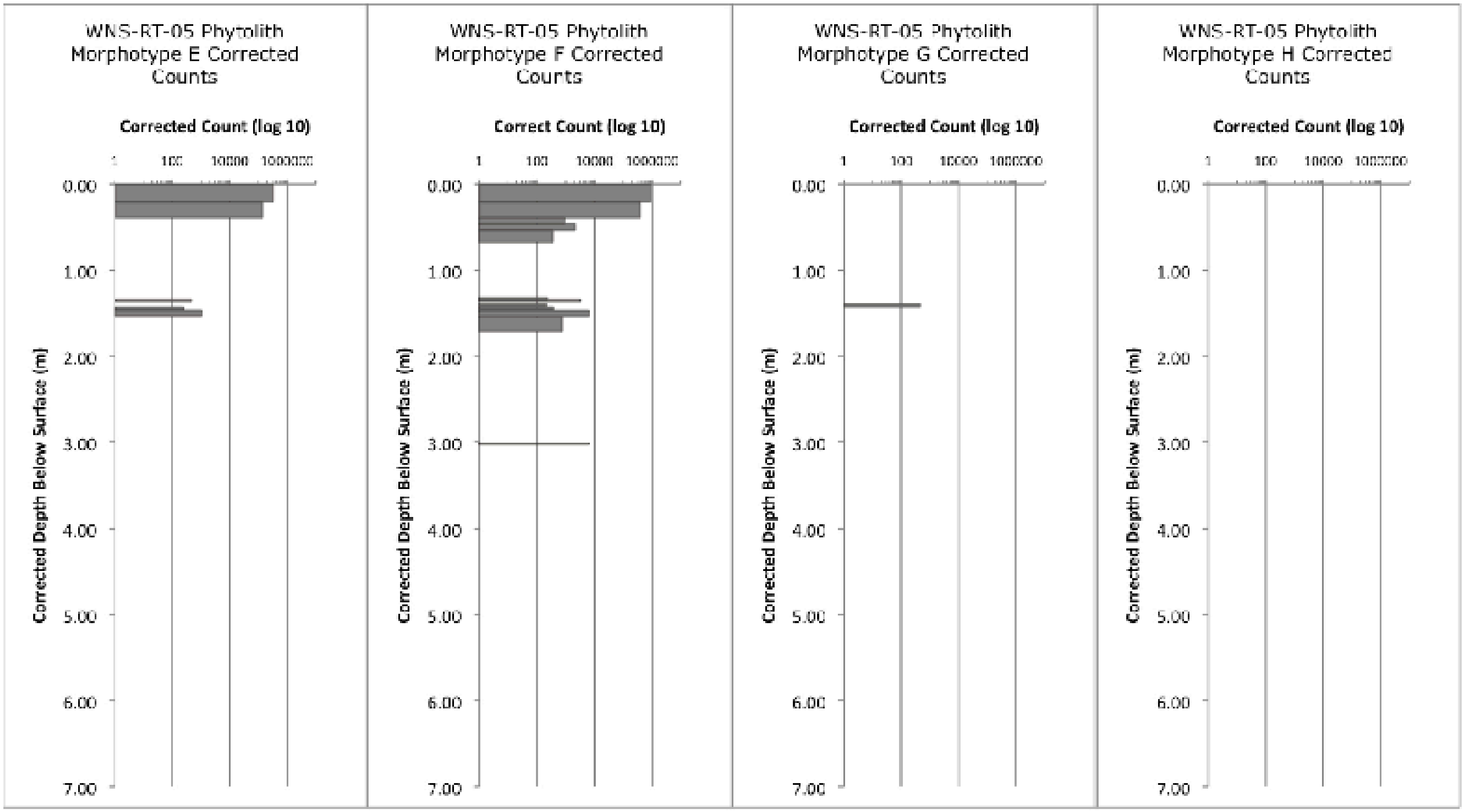


Figure 5.10. Corrected counts of short-cell phytolith morphotypes E, F, G and H in samples from WNS-RT-05. The height of each bar represents the thickness of the segment of sediment and its depth below surface.

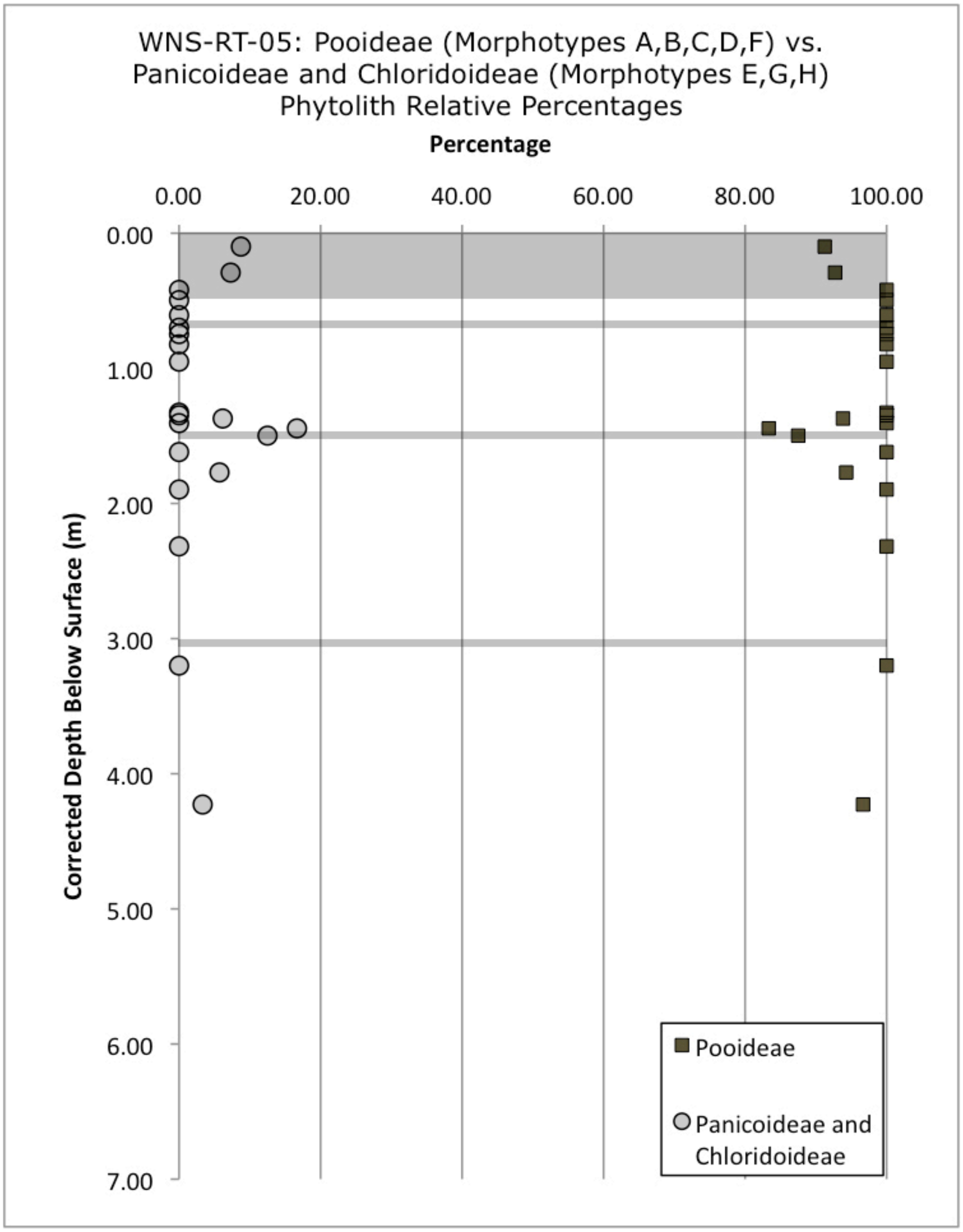


Figure 5.11. Percentages of Pooideae phytolith morphotypes (A, B, C, D and F) versus the combined percentages of Panicoideae and Chloridoideae phytolith morphotypes (E, G and H).

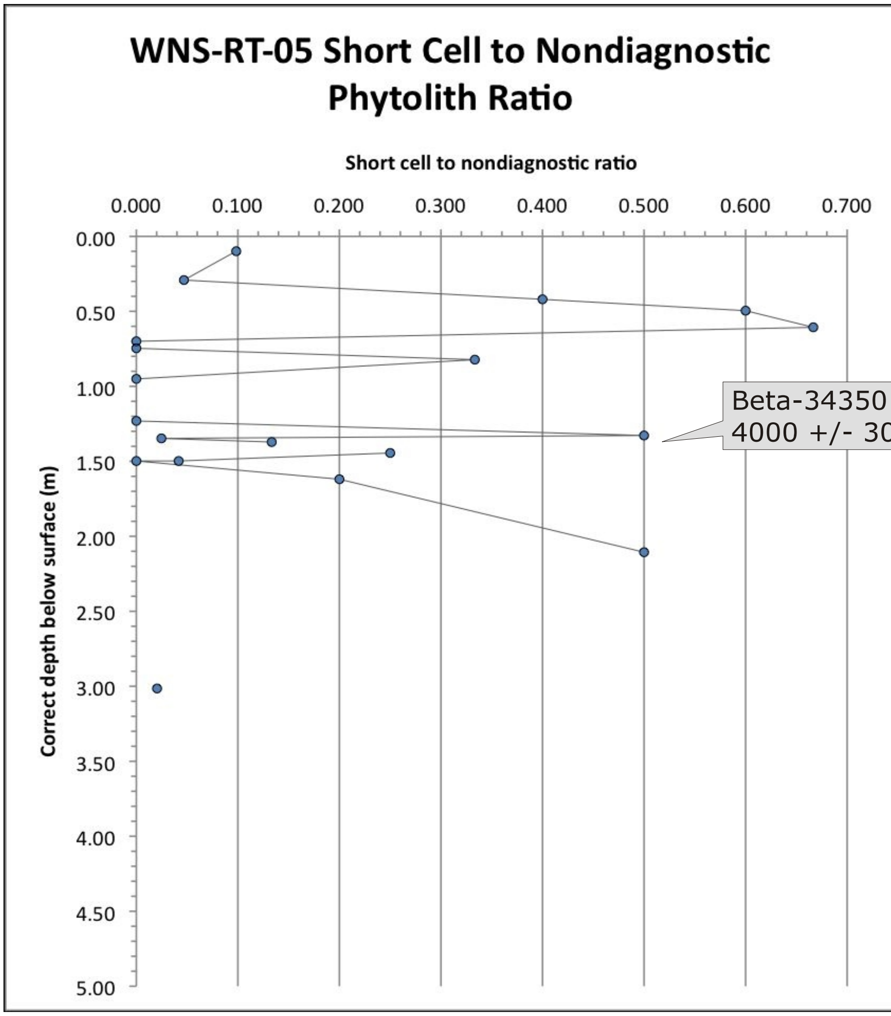


Figure 5.12. Ratio of short-cell phytoliths to all other phytolith forms found in WNS-RT-05.

Chapter 6: Interpretation

6.1 Introduction

The objectives of this study include developing geomorphic, paleoenvironmental and paleoclimatic interpretations of data recovered from the analysis of subsurface cores from the Red Tail site. This chapter uses the results presented in the previous chapter as the basis for these interpretations. It also attempts to relate them to the previously excavated material from the Red Tail site. Additionally, it critically evaluates the methods used to analyze the cores, commenting on their strengths and limitations in terms of the goals of this study. Lastly, it looks at the paleoenvironmental and paleoclimatic history of the site in relation to what is known about Hypsithermal and later climate change on the Northern Plains, exploring if these data help explain why the Red Tail site is only one of a large number of Middle to Late Precontact archaeological sites clustered in Wanuskewin Heritage Park.

6.2 Geomorphic Interpretation

The geomorphic interpretation of the Red Tail site is based on analysis of topographic maps and air photos of the study area, knowledge of its present landforms, descriptive logging of two Geoprobe cores from the Red Tail site, and information from two prior archaeological and geomorphic studies of the Red Tail site (Burt 1997; Ramsay 1993). Core WNS-RT-05 is used as the main source of information, as it was subjected to more extensive analysis, but the basic descriptive logs produced for Core WNS-RT-03 serve as a point of comparison. All depths presented are the depths below surface, corrected for compaction during coring (see section 5.2). The two cores were taken approximately 4 m apart, but considerable variation between the two cores is apparent. This attests to the substantial horizontal variation in the soil and sediment deposits at the Red Tail site, largely due to its position on a hillslope.

6.2.1 Late Pleistocene Glaciolacustrine Sediments

The Red Tail site is located within a less steep area about midway down a small north-south-oriented valley leading into the South Saskatchewan River (Figure 2.3 and 4.1). At the floor of this small valley lies in the channel of an ephemeral stream which currently only carries water in spring. During Ramsay's 1993 excavation of the Red Tail site, evidence of Middle to Late Precontact human occupation was found in 15 layers located within the top 2 m of the sediment deposited in this mid-slope area. Below the top 2 m lies a complex record of earlier geomorphic activity, which prior to the present study had not been investigated. In this part of central Saskatchewan, the surficial deposits are reported to contain "deglacial lacustrine, outwash, and ice-content sediments and postglacial alluvium, colluvium, eolian, and landslide deposits" (Christiansen 1992: 1776). Cores WNS-RT-03 and WNS-RT-05 both extend to approximately 6.5 m below surface, recovering a valuable sample of these kinds of surficial material. In particular, within the cores there is evidence of glaciolacustrine deposits followed by postglacial alluvium and colluvium.

While the cores were being extracted in the field, the recovery of the final and deepest core drive was complicated by clay-rich deposits. In WNS-RT-05, these clays begin at the base of the core and extend to approximately 5.7 m below surface. These massive clays are a record of a low-energy depositional environment, likely the glacial lake that covered the Saskatoon area in the Late Pleistocene. During this period the receding Laurentide Ice Sheet impounded meltwater, which created expansive glacial lakes. The relatively still waters of the glacial lake environment allowed the deposition of its suspended fine-grained sediment load on the lake floor.

6.2.2 Late Pleistocene and Early to Middle Holocene Sediments

As the glacial ice sheets continued to melt and recede across the Northern Plains during the Late Pleistocene, the release of large volumes of impounded meltwater from bodies such as glacial lakes led to the often rapid and catastrophic movement of this water in the form of high-energy glacial outflow (Christiansen 1992). This period of high-energy, high-volume water movement resulted in the downcutting of channels that carried the released meltwater, such as the South Saskatchewan River Valley (see Figure 2.2). As the South Saskatchewan River Valley became incised into the land surface, the sides of the valley would have become over-steepened, resulting in slumping along the valley sides (see section 2.3.1 Hillslope Processes). This is a phenomenon that continues to be an issue in other areas along the banks of the South Saskatchewan River Valley today and it presumably would have been more severe during the Late Pleistocene to Early Holocene downcutting of the channel.

The Red Tail site's location on a small relatively flat mid-slope area along the river valley suggests that it is situated on the top surface of a rotational slump block. This slumping appears to have occurred during the Late Pleistocene to Early Holocene downcutting of the river valley based on the fact that its basal clays are overlain with considerable alluvial and colluvial deposition. The slumping may have occurred during a period of low water levels, or it may have occurred subaqueously during a period when water levels in the South Saskatchewan channel were high. Figure 2.2 indicates the position of the Red Tail site during the incision of the South Saskatchewan River Valley, which was located underwater during much of the development of the valley. Either scenario results in the mass movement of material down the over-steepened valley slope. Evidence of subaqueous slumping would appear as flame structures, a form of soft sediment deformation in which flame-shaped plumes of a lower layer rise upward into the sediment that comes to rest on top of it (Picard and High 1973). In general, this overlying layer is a rapidly moving deposition of sand, although in this case it would have been clay rapidly deposited on top of other clay. Identification of such evidence would not be possible within the limited sample of the core; further exposure or subsurface testing of sediments would need to occur. Delineation of the topographic extent of the original slump block also would be difficult without considerable further subsurface testing to the depth of the cores and beyond, since millennia of alluvial, colluvial and slopewash activity would have obscured the surfaces and edges of the original block, making it difficult to identify.

As the slump block slid down the steep valley side, the glaciolacustrine sediments would have remained at the bottom of the block, surmounted by a veneer of clast-rich glacial till that is currently exposed at the surface of the plain adjacent to the South Saskatchewan Valley in this area. While there is no evidence of this till within the cores, the small circumference of the core samples makes it difficult to recover clasts of the size characteristic of this till. It is also possible that the glacial till was washed away from the top of the slump block as river waters surged over it during Early Holocene meltwater drainage events.

This kind of slumping results in a stabilized slope, upon which either deposition or erosion can occur. If the slumping occurred during a period of high water levels, alluvial deposition or erosion would have continued as the river washed over the slumped material. At the Red Tail site, coarse sands and gravelly sediments overlie the glaciolacustrine clays from about 5.7 m to 3.25 m below surface in core WNS-RT-05 (Figures 5.2 and 5.3). The larger particle size of these coarse sands and gravels, coupled with the presence of horizontal laminations characteristic of alluvial bed forms from 4.2 to 3.8 m below surface in WNS-RT-05, suggest that relatively high energy alluvial processes were responsible for their deposition. The high-energy glacial outflow responsible for the downcutting of the river valley would have moderated as the Laurentide Ice Sheet retreated, allowing a shift from channel downcutting to deposition of this kind of sediment load during the Late Pleistocene to Early Holocene. These alluvial deposits make up a considerable proportion of the sediments found in the cores from the Red Tail site.

The portion of these alluvial deposits which directly overlies the fine, clay rich sediments, starting at approximately 5.7 m below surface, is described as coarse sand and very gravelly (greater than 20%), with gravels measuring up to 10 mm in diameter. These initial alluvial deposits, most likely laid down in the Late Pleistocene, are delineated by a clear and abrupt lower boundary and have a distinct reddish, orange colour, which appears to be a product of their post-depositional environment (Figure 5.3). The underlying clay layer creates an impermeable boundary against which groundwater becomes impounded. This allows the coarse sands, through which water flows easily, to become seasonally saturated by groundwater, then re-exposed to air, resulting in iron oxidation and the distinct colouration.

Figure 5.2, the stratigraphic column of WNS-RT-05, illustrates the fairly consistent texture of the sediment layers between 5.7 and 3.25 m below surface. These sediments are consistently identified as loamy sand or sand, with varying percentages of gravel. Automated particle size analysis results of these sediments are almost all above 90% sand (Appendix 2). This consistent deposition of coarse sand is also found in the lower drives of WNS-RT-03, although it includes one smaller interval of finer sediment deposition at approximately 4.0 to 3.8 m below surface. However, those finer sediments in WNS-RT-03 are found at the top of the fifth core drive, suggesting that they may have been erroneously identified and should have been removed as slop.

As noted above in drive 5 of WNS-RT-05, from roughly 4.2 to 3.8 m below surface (Figure 5.2 and 5.3) fine horizontal laminae, each less than 2 mm thick, appear within deposits of coarse sands. These laminations could indicate one of two depositional environments. It is possible that they were formed by periodic, but regular, overbank floods or if water levels were consistently high and the area was submerged, these laminations could also be a product of channel aggradation. The first scenario presumes that water levels in the South Saskatchewan channel had dropped below the level of where the Red Tail site currently sits. During periods of high water, whether due to seasonal or less frequent flood episodes, overbank flow could produce laminations in the deposits by forming a series of very small fining upward sequences. Alternatively, if the water level during this period remained high enough to cover the site, these laminations could be a result of regular, likely seasonal variations in flow velocity and sediment load in the channel.

Above the horizontally laminated sands lie massive sands extending from 3.8 to 3.25 m below surface. Above 3.25 m below surface, there is a shift to sediments with smaller particle sizes. WNS-RT-05 shows a distinct fining upward sequence in both the stratigraphic column (Figure 5.2) and the automated particle size analysis (Figure A2.1) between roughly 3.25 and 3 m below surface. This is an indication of decreasing energy of deposition and suggests a single episode of overbank flooding from the nearby South Saskatchewan River or from the nearby ephemeral stream; however, the thickness of this fining-upward sequences suggest flooding of a volume beyond the capacity of the ephemeral stream unless its channel and discharge were significantly greater in past. This type of deposition indicates that by this point water levels had dropped and the Red Tail site area was now on the bank of the South Saskatchewan River.

The segment of the core directly above this fining upward sequence, from approximately 3.0 to 1.5 m below surface, shows some variation in texture suggesting a variety of depositional processes. Poorly sorted, gravelly material suggests colluvial deposition, while finer sediments could be from either alluvial or aeolian sources. There are no soils preserved in this portion of the core, which may be because the surface was not stable enough to support the development of a soil, or it could be due to removal of soils by subsequent erosion. Regardless this segment of sediment most likely coincides with the Early to Middle Holocene, a period of climate variability, including intervals of conditions warmer and drier than at present (see section 2.4.1 Early and Middle Holocene Climate Change). This variability in climate, particularly the warm, dry intervals, likely resulted episodes of decreased vegetation and increased potential for transport of exposed sediment by wind, water or gravity, which in turn is consistent with the diverse deposits in this section of core WNS-RT-05. If so, the massive sands from 3.8 to 3.25 m below surface in WNS-RT-05 may also indicate Middle Holocene aeolian deposition, as their lack of structure and texture are consistent with wind-borne deposits.

The lack of evidence of multiple buried A-horizons in this portion of the core contrasts with portions of the core higher than 1.5 m below surface, demonstrating that the site only latterly experienced episodes of landscape stability long enough for vegetation and soil formation processes to establish themselves. Alternatively, episodes of soil erosion in periods of devegetation or intervals of stability in periods unfavorable to the development of vegetation may have created this patterning in the sediment beneath 1.5 m below surface. The lack of evident unconformities in these lower sections of the cores means there is no direct evidence for these scenarios. However, their location below the buried soil yielding a radiocarbon date of 4000 +/- 30 B.P. again suggests that supports the hypothesis that they were deposited during the Hypsithermal, when dry conditions would have encouraged lack of vegetation and ready erosion of exposed land surfaces.

Importantly, it is possible that no deposition occurred during the warm, dry period of the Hypsithermal. Or, alternatively, if occasional deposition did occur, the warm, dry climate may have resulted in desiccation and aeolian removal of these deposits. While no evident erosional contacts were observed within the cores, it is possible that this is again due to the limited observation the narrow cores provide. If either of these scenarios are the case, it suggests that the middle segments of the cores are either Early or Late Holocene. This situation also would have implications for paleoenvironmental and paleoclimatic study of the period in this region, since it implies that terrestrial deposits with suitable proxy indicators might be scarce for this time frame.

6.2.3 Middle to Late Holocene Sediments

Based on the radiocarbon date of 4000 +/- 30 B.P. from a sample 1.3 m below surface (Figure 5.2), combined with radiocarbon dates and information from two previous studies at the Red Tail site (Burt 1997; Ramsay 1993), approximately the top 2 m of sediment at the site and in these cores was likely deposited over the last 5 000 years. It is within these top 2 m of sediments that most of the stable isotope and phytolith analysis was conducted, since they contain multiple buried soils created by the vegetational communities that phytolith and stable isotope analysis can help identify; these are also the depths that have yielded the evidence of human occupation at the Red Tail site, allowing examination of this activity in light of the paleoenviroment data provided by these techniques. As of about 5 000 B.P., the study area experienced a shift from Hypsithermal conditions to cooler, moister climate conditions. This pattern of climate change would have been more conducive to vegetation growth and pedogenesis. These processes would, in turn, have contributed to increased slope stabilization and erosion control by encouraging ground cover and root mass that would have protected and retained sediment.

Since 5 000 B.P., the deposition occurring at the site has been due to a combination of lower energy alluvial and occasional colluvial processes. These lower energy alluvial and occasional colluvial processes are evidenced by the appearance of finer, silty layers of sediment interspersed between buried A-horizons (Figure 5.2). Several layers of sediment contain more than 20% gravel, indicative of a higher energy process such as debris flow. These processes have been intermittent, with periods of subsequent landscape stability and vegetation development evidenced by soil formation. This combination of stability and deposition offers ideal circumstances for preservation of archaeological material in stratified layers, and it also provides an archive for paleoenvironmental and paleoclimatic analysis by creating sequences of buried soils that reflect the vegetation communities under which they formed. The complex stratigraphy of the site in both the cores and the archaeological excavation demonstrates that periods of landscape stability and human occupation were followed by episodes of deposition, creating layers of evidence preserved for later inquiry.

Late Holocene flooding of the South Saskatchewan River would have created overbank deposits at sites such as Red Tail. Despite the lack of flooding in the area during modern times, episodic flooding would have been a considerably more common occurrence prior to the construction of the Gardiner Dam in 1967, which now controls water flow by reducing down stream flow of the South Saskatchewan River. This would have been especially marked during the Early Holocene, when the river would have been draining the meltwater that the retreating Laurentide Ice Sheet continued to release across the region. However, episodic flooding would have been a factor after this time as well, because, prior to the dam's construction, considerable rainfall or rapid snowmelt would have caused flooding along the South Saskatchewan River Valley (see section 2.3.2 and Figure 2.5).

Flooding of the South Saskatchewan River would not be the only source of deposition at the Red Tail site during the past 5 000 years. The site location is also in close proximity to the previously mentioned small ephemeral stream, which allows for the possibility of seasonal alluvial deposition from this source.

The Red Tail site is also located on a valley side sloping towards the South Saskatchewan River from the till plain that extends north of the valley. Periodic colluvial deposition, such as debris flows, which were identified as a predominant depositional process by Rutherford (2004), would have resulted in deposition of larger and more poorly sorted particles than the alluvial processes outlined above. Notably, they would have had the energy to create the occasional gravels seen in the upper parts of both cores, while their upslope origins would have provided them with a source of clasts from till. Another form of hillslope deposition that probably contributed to the formation of the Red Tail site is slope wash, which results from the combination of seasonally available water and the action of gravity. This type of slope process often produces relatively well-sorted, finer grained alluvial deposits.

The frequent depositional input from a number of different sources appears to have limited the amount of time the land surface remained stable, confining episodes of pedogenesis to a limited period. Without adequate time to develop, A-horizons remained shallow and did not develop well-established B-horizons (Figure 5.2). This contributes to the challenge of identifying the buried soils within the cores and also precludes identifying the plant communities under which these Regosols formed based solely on their soil morphology.

While not ideal for substantial soil development, this established pattern of intermittent deposition alternating with interspersed periods of landscape stability is ideal for the preservation of archaeological sites. Figure 6.2 illustrates the frequent buried A horizons identified during the archaeological excavation. Far fewer buried A-horizons were identified in the Geoprobe cores, which may be due to horizontal variation across the site area, as well as compaction and distortion of the soils and sediments in the cores, which can make precise identification of discrete Regasols problematic.

Periods of landscape stability not only facilitate human occupation, but also allow for the development of soils and vegetation on each newly created land surface. The types of vegetation successful in populating these land surfaces are reflective of the climate conditions during each of these time periods. The subsequent burial of these once-stable surfaces by either alluvial or colluvial deposition offers the optimal conditions for preservation of not only archaeological sites, but also the paleoenvironmental and paleoclimatic evidence contained within the once-active soils.

6.3 Paleoenvironmental Interpretation

One of the objectives of this study was to determine whether or not the sediment/soil description coupled with phytolith and stable carbon isotope analysis would be effective in providing useful paleoenvironmental and paleoclimate data from sediments within the study area. The previous chapter presented the results of these analyses and this chapter both interprets these results and assesses the techniques' utility for research in this region.

6.3.1 Pedostratigraphic Analysis

The first objective for paleoenvironmental interpretation of the cores was to identify probable buried A-horizons within the core. As discussed above, buried A-horizons provide the potential for identifying past stable land surfaces that could have supported human occupation. Also, although the buried soils in these cores are thin Regosols and their morphology therefore cannot inform us about the vegetation under which they formed, they have the potential to yield stable carbon isotope and phytolith data, which, in turn, offer insights on the nature of the plant communities that lived on these surfaces.

During the descriptive logging of the cores, the first characteristic used to identify these probable buried A-horizons was their colour. Buried A-horizons have a higher proportion of organic matter and therefore appear darker than other bands of sediment. Rich, dark brown or black horizons, as defined by the Munsell Colour Chart, were initially identified as being probable buried A-horizons.

Automated carbon content analysis was conducted in order to provide quantitative data on the organic and inorganic carbon in the samples from WNS-RT-05; results of this analysis are presented in Figure 5.2. A major component of soil organic matter is carbon; it is not only an important element in plant growth, but is also returned to the underlying soil when plants die resulting in carbon enrichment of the A-horizon. This process makes organic carbon content of the sediments an important line of evidence in classifying potential buried A-horizons, since they should have higher organic carbon concentrations than surrounding sediments (Holliday 2004: 88). Figure 5.2 shows that higher organic carbon content percentages are associated with the sediments from the cores that were initially identified as potential buried A-horizons based on colour.

The soils closest to the surface have the highest percentages of organic carbon content, while the buried A-horizon samples lower in the column have decreasing organic carbon percentages. However, these deeper A-horizon samples are still identifiably higher in organic carbon content than the surrounding C-horizon sediments. The decreased organic carbon content values lower in the column may be due to diagenetic loss of organic material following burial of the soil (Holliday 2004).

Another indicator used to identify buried A-horizons is the upper and lower soil boundaries. Buried soils should have a sharp upper boundary created when the soil was buried by other sediments, ending pedogenesis. In contrast, their lower boundaries should be gradual, reflecting downward movement of their chemical constituents during the process of pedogenesis (Holliday 2004: 85). The descriptive core logs (Table A.1 and A.2) of WNS-RT-03 and WNS-RT-05 record the lower boundaries of each layer of sediment. In most cases, the samples identified as buried A-horizons are recorded as having a gradual lower boundary and an abrupt or clear upper boundary.

The final line of evidence to support identification of potential buried A-horizons is the numbers of phytoliths. As phytoliths are contributed to underlying soils as a result of plant growth, death and decay, buried A-horizons should have high numbers of phytoliths, whereas C-horizons should not (see section 2.4.3.4 Phytolith Analysis Background). Figure 6.1 demonstrates the peak numbers of corrected counts of phytoliths and their correlation with potential buried A-horizons (see section 5.5 Phytolith Analysis Results).

The majority of the potential buried A-horizons identified in the core appear in roughly the top 1.5 m of the core (Figure 5.2). Prior to this point, deposition and erosion occurred frequently indicating a much more dynamic environment during the earlier half of the Holocene. Soil development occurs more commonly in the latter half of the Holocene, once the climate started to become cooler and moister, and the landscape became stable enough to support vegetation growth.

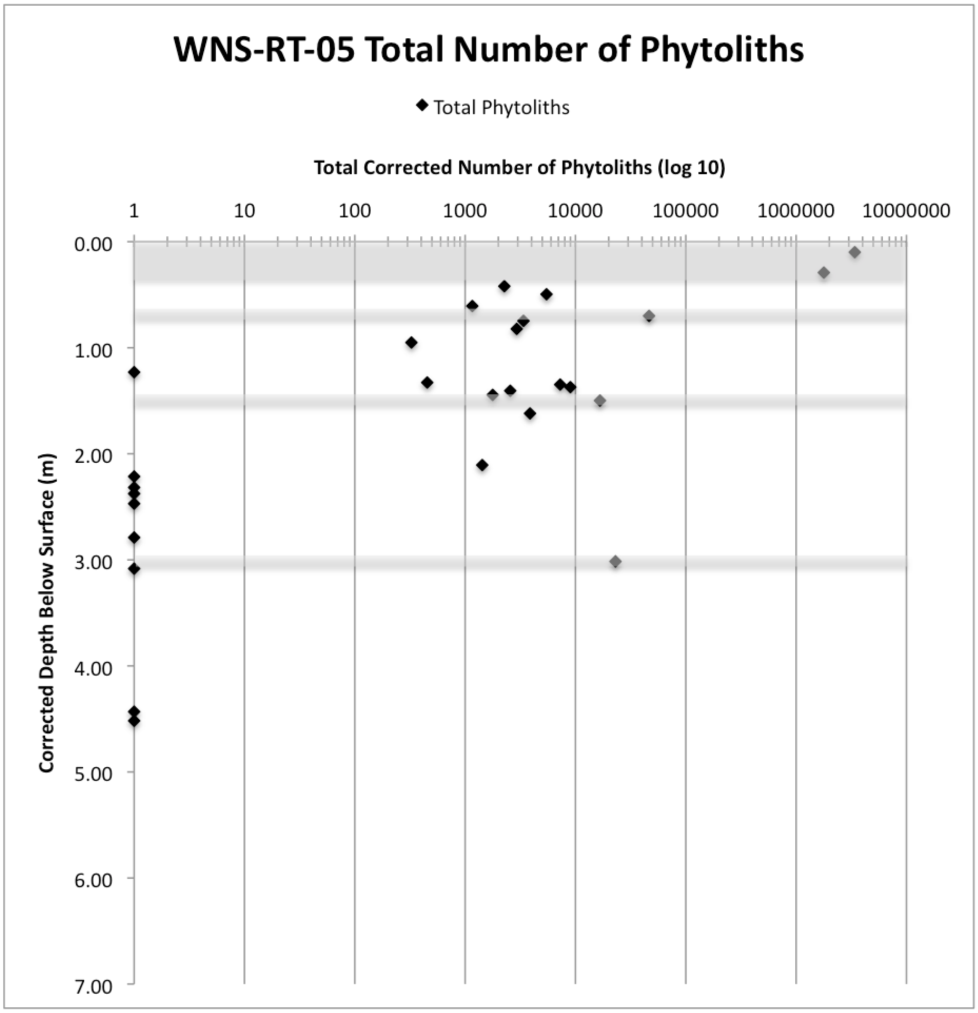


Figure 6.1. Total phytolith correct counts (all morphotypes). Shaded areas indicate potential buried A-horizons.

6.3.2 Interpretation of Stable Isotope Analysis Results

The photosynthetic pathways of plants differ based on the climates and environments to which they are adapted. Specifically, C_3 plants generally prefer cooler, wetter conditions and use a photosynthetic pathway that discriminates more strongly against $^{13}CO_2$, whereas C_4 plants typically prefer warmer, drier conditions and use a photosynthetic pathway that discriminates less strongly against $^{13}CO_2$. Their varying levels of ^{13}C uptake are recorded in their tissues and passed to the soil organic matter of the soils they grow on. The relative proportions of C_3 and C_4 plants that grew on a buried A-horizon are therefore indicated by $\delta^{13}C$ values, an expression of the fractionation between ^{13}C and ^{12}C (Holliday 2004: 225). The stable isotope analysis results from WNS-RT-05 (Figure 5.4) show fairly consistent $\delta^{13}C$ values throughout the history of deposition at the Red Tail site. The range of values for C_3 vegetation, which includes trees, shrubs, forbs and cool climate grasses, is -35‰ to -20‰, with an average value of -27‰. The values from the Red Tail site deposits range from -27‰ to -22.8‰, falling within the range for C_3-dominated vegetation.

Any incursion by C_4 plants would be indicated by an upward shift of these values, since these drought-tolerant, warm-climate grasses produce $\delta^{13}C$ values in the range of -9‰ to -16‰. C_4 plants offer an important proxy indicator of paleoclimate because their abundance is "strongly and positively related to environmental temperature" (Holliday 2004: 225). The lack of values approaching or in the range of C_4 plants indicates that there is no stable isotope record of warmer, drier climates that led to a marked shift in vegetation away from C_3-dominated plant communities.

Using Landi et al.'s (2003a) conversion equation in order to calculate the percentage of C_3 versus C_4 plants in the past vegetation communities at the Red Tail site (see section 5.4 Stable Isotope Analysis Results), the results show a consistent dominance of C_3 plants for all samples analyzed (Table 5.2). The results of the calculations demonstrate a range of 70.29% to 100% C_3 plant communities at the site. Figure 5.6 demonstrates a trend in the data from approximately 4.5 to 1.4 m below surface moving from a basal value of 100% C_3 vegetation, indicative of a cool, wet environment, to the high value of 70.29% C_3 plants at about 1.44 m below surface, indicating vegetation decreasingly dominated by C_3 plants. Given that this high value occurs just below the radiocarbon date of 4000 +/- 30 B.P., provided by a sample from about 1.3 m, this patterning may indicate a transition from the cool, wet climate of the post-glacial period to the increasingly warm, dry climate of the Middle Holocene. This period of warm, dry climate is also reflected in the soil/sediment record between about 3 and 1.5 m below surface, which suggests a diversity of depositional processes consistent with a period of climatic variability (see section 6.2.2 Late Pleistocene and Early to Middle Holocene Sediments).

The low percentages of C_3 vegetation found just prior to the radiocarbon date of 4000 +/- 30 B.P. are still indicative of predominantly C_3 vegetation, but they do suggest a slight deflection towards a higher proportion of C_4 plants. Based on their position within the core, this would place those deposits at the end of the Hypsithermal period, suggesting that the warmer, drier climatic intervals associated with this period contributed to slightly lower concentrations of C_3 vegetation. As noted in Chapter Two, the Hypsithermal was a period of variable climate, so this particular soil may have been formed during a later upswing in temperature and aridity toward the end of the period (see section 2.4.1 Early and Middle Holocene Climate Change).

While the $\delta^{13}C$ values from samples of buried A-horizon are indicators of the photosynthetic pathway utilized by the plants that dominated the vegetation while the soil was forming, both probable buried A-horizons and C-horizons were sampled for stable isotope analysis. The $\delta^{13}C$ values from C-horizon samples, while not direct reflections of the plant communities that once flourished on stable surfaces at the study site, indicate a number of possibilities. The C-horizons that separate past stable land surfaces are composed of sediment transported to this location from elsewhere. The $\delta^{13}C$ value recovered from the C-horizon samples may therefore be a record of the vegetation at the location from which the C-horizon sediment originated. Alternatively, the $\delta^{13}C$ value could also reflect a record of the photosynthetic pathways of plants that grew intermittently on the C-horizons, but were not well established enough to result in sufficient soil formation to leave an identifiable buried A-horizon. Regardless, these samples produced $\delta^{13}C$ values typical of C_3 plant-dominated communities, further supporting the consistent presence of such communities in and around the site.

6.3.3 Interpretation of Phytolith Analysis Results

Climate conditions at a location have a direct effect on the type of plants that become established. During periods of land surface stability at the Red Tail site, varying climatic conditions would have resulted in different vegetation at different points in time, with implications for the soils that formed under these plant communities. In the event of substantial climate change in areas with substantial percentages of grasses, changes in the proportions of grass species with different climatic tolerances will occur, generating variations in the short-cell phytolith types that these grasses leave in the underlying soils when they die and their tissues become integrated into these soils. In the Great Plains of North America, including the Northern Plains, previous research has indicated that the percentages of short-cell morphotypes extracted from soils indicate the percentages of the grass subfamilies under which these soils formed (see section 4.2.5 Phytolith Analysis Procedure).

Based on this previous work, especially that of Fredlund and Tieszen (1994), the phytolith data in this study were used to infer climate conditions from percentages of the associated grass subfamilies. Phytolith assemblages in WNS-RT-05 are consistently characterized by high percentages of morphotypes A (keeled) and C (pyramidal), a pattern associated with Pooideae grass dominant plant communities (see section 2.4.3.4 Phytolith Analysis Background). Pooideae grasses are C_3 plants which thrive in cool temperatures with high soil moisture content (Piperno 1988: 213). In several samples morphotype A or C phytoliths make up more than 50% of the phytolith assemblage. Though not as abundant as morphotypes A and C, there are several samples in which morphotype B (conical) and morphotype D (crenate) phytoliths make up a portion of the assemblage. High ratios of conical and crenate phytoliths are also associated with Pooideae grasses and therefore suggest cool temperatures and high moisture levels.

Many samples also include high percentages of morphotype F, or *Stipa*-type phytoliths. These phytoliths are associated with the genus *Stipa*, a member of the subfamily Arundinoideae that includes species such as *Stipa viridula* (Green Needle Grass), *Stipa comata* (Needle and Thread), and *Stipa curtiseta* (Western Porcupine Grass), which are common on the Northern Plains. These grasses are also associated with cool, moist climate conditions, a pattern consistent with the high numbers of morphotype A, B, C and D phytoliths found in many of the samples.

Morphotype E, saddle-shaped phytoliths, appear very infrequently in the samples from WNS-RT-05. An abundance of these phytoliths, which are characteristic of Chloridoideae grasses, would indicate a warm, arid climate. The lack of any significant contribution by Chloridoideae grasses suggests that periods of persistently warm, arid climate are not recorded in the sediment at the Red Tail site.

There were no morphotype H, or Panicoid-type, phytoliths found within the samples from WNS-RT-05. Also, only one sample yielded just two examples of morphotype G, the simple lobate form also associated with Panicoid grasses. Panicoids are tall grasses that thrive in warm temperatures with high soil moisture; the paucity of these morphotypes indicates that the sediment at the site does not record any periods during which the climate was conducive to their growth (Bozarth 1993: 95; Fredlund and Tieszen 1994; Alam et al. 2009: 509).

In an effort to make this phytolith data more easily comparable to the stable carbon isotope analysis results, Pooids are compared with the combined relative percentages of Panicoids and Chloridoids (Figure 5.11). While this is a simplification of the phytolith data, in general, Pooids represent C_3 grasses, while Panicoids and Chloridoids are predominantly C_4 grasses. This allows comparison between the phytolith analysis data and the stable carbon isotope analysis data that informs on C_3 versus C_4 plant dominated communties. This figure clearly demonstrates the consistently high percentages of morphotypes A, B, C, D, and F, a pattern which suggests the prevalence of C_3 grass species that thrive in cool temperatures with high soil moisture content. There is a slight deviation from this pattern in two samples between 1.39 and 1.46 m below surface. Specifically, morphotype G makes up 16.67% of the relative percentage of the top sample and morphotype E makes up 12.5% of the relative percentage of the sample directly below. Neither sample contains any other C_4-associated morphotypes, and the small percentages of Chloridoid and Panicoid morphotypes does not constitute a large enough deflection to indicate a substantial shift to C_4-dominated vegetation. It may, however, reflect a subtle change in the climate during the period of soil development reflected in those samples. This is more fully discussed below in correlation with stable carbon isotope results.

While grasses are an important factor of Northern Plains ecology, they are not the only species of plant present on the Northern Plains, nor are they the only producer of phytoliths. Trees and shrubs may also produce phytoliths, though they are not short-cell forms and therefore do not fit into the morphotype classification laid out by Fredlund and Tieszen (1994). The Red Tail site is located very near the boundary between the mixed grassland and aspen parkland ecozones, and along a well-watered river valley, making trees and shrubs an important part of the vegetation (see section 2.5.1 and Figure 2.10). While this is outside the scope of this preliminary study, which is based on the well-tested grassland-focused approach of Fredlund and Tieszen, the site's location makes consideration of non-short-cell phytolith forms important.

Figure 5.12 shows the ratio of short-cell phytoliths to non-short-cell phytoliths in the analyzed samples in order to determine if these ratios can offer insights about non-grass species present at the site and their increasing or decreasing representation through time relative to the grasses represented by the short-cells. Very few non-short-cell phytoliths were counted during analysis of the slides, perhaps due to their scarcity, observer inexperience in their identification and/or the fragility that sometimes limits the preservation and identification of non-short-cell forms. Also, in addition to short-cell phytoliths, grasses also produce non-short-cell forms, meaning that the proportion of short-cell to non-short-cell types does not give an entirely precise indication of grass versus non-grass species' presence. These issues limit the conclusions that can be drawn from this line of analysis, but major changes in the proportion of short-cell to non-short-cell phytoliths may give some clues about major shifts in the proportions of grass versus trees and shrubs at the site. In Figure 5.12, upswings in the ratio potentially indicate a higher concentration of grasses, while a downswing may indicate the opposite. Higher values are evident at approximately 0.5 m, 1.25 m and 2.1 m. These particular samples yielded very low numbers of both short-cell and non-short-cell phytoliths, making them unreliable sources of information for this analysis. This is most likely due to observer inexperience in identification of non-short-cell phytoliths and the concentration of this study on short-cell identification and analysis. Suggestions for further non-short-cell phytolith research as discussed in Section 7.5 Areas for Future Research.

6.3.4 Integration of Stable Isotope and Phytolith Results

Both the stable isotope and the phytolith data show that the deposits at Red Tail fairly consistently record C_3-dominated vegetation. These results suggest a fairly consistently cool, moist climate without enough fluctuation to allow for significant incursion of C_4 species, at least during the Middle to Late Holocene, when an extended sequence of buried soils provide a reasonably complete record of conditions at the site. The site was geomorphically very active during the Late Pleistocene and Early to Middle Holocene, as previously discussed, which resulted in a lack of soil development and therefore no robust proxy data from which paleoenvironment and paleoclimate could be inferred. However, the similarity of the data retrieved from the stable isotope and phytolith analysis in the upper part of the site's record demonstrates the effectiveness of the combination of these proxy indicators in establishing a paleoenvironmental record.

There is, however, a slight deflection in both the stable isotope and phytolith evidence of C_3 vegetation dominance (Figure 5.4 and 5.11) just prior to the radiocarbon date of 4000 +/- 30 B.P. At this point in core WNS-RT-05, the stable carbon isotope analysis suggests a plant community containing approximately 70% C_3 vegetation, which is somewhat lower than at other points in the core. Those same samples show a slight increase in the relative percentage of Panicoid and Chloridoid phytoliths, also suggesting the potential for a period of slightly warmer and drier climate.

This period of slightly warmer and drier climate would fall near the end of the period defined as the Hypsithermal. There is no other evidence of warm, arid climate found within the lower sediments recovered in the core, which may have been expected during the peak portion of the Hypsithermal. However, it is entirely possible that these sediments have been removed from the area due to erosion. The results otherwise indicate a fairly consistent record of cool, moist climate, supporting the suggestion that the Opimihaw Creek Valley and adjacent South Saskatchewan River Valley offered Middle Precontact period groups an attractive environment. The mild climate and rich biodiversity offered by the area would certainly be of interest to migratory groups and may explain the rich concentration of archaeological material found within the 19 identified Precontact sites within Wanuskewin Heritage Park.

As discussed in section 2.4.1, paleoenvironmental records on the Northern Plains tend to show a variable climate throughout the Hypsithermal, rather than one long severe period of drought. This episodic variability may be reflected in WNS-RT-05 with the indication of warmer, drier climate and environmental conditions just prior to 4 000 B.P. Most records point to a period of peak aridity between 8 000 and 6 000 years ago, with a return to more moderate climates around 4 500 years ago. The paleoenvironmental proxy data recovered from the Red Tail site correlates well with what is already established in the region, with evidence of consistent cool, moist climate established by at least 4 000 B.P.

6.3.5 Evaluation of Methods

Although there have been two previous studies conducted at the Red Tail site, the present study is the first to be able to explore the archaeologically sterile sediments found below the depth of 3 m that was reached by the original excavation of the site. The benefit of coring is that subsurface investigation can extend to substantially deeper deposits, allowing for a much more complete geomorphic history of the site, without the time and expense associated with an archaeological excavation. A major limitation is that, while such cores are great in depth, their limited width and the physical distortion induced by the coring process makes observation of some sediment features and structures difficult, if not impossible. Despite these limitations, Geoprobe coring offers a window that extends much further into the past than traditional excavation methods. This has allowed an unprecedented glimpse of the Late Pleistocene to Middle Holocene history of not just the Red Tail site but also its immediate vicinity.

The combination of stable isotope and phytolith analysis has proven to be an effective combination in prior studies and it was successful in once again providing corroborative paleoenvironmental and paleoclimatic data. Both lines of evidence produced evidence of a fairly consistent C_3-dominated vegetation, from which can be inferred a cool, moist climate throughout the portions of the Holocene for which depositional layers exist at the site. There is the possibility that the warm, dry climate of the Hypsithermal resulted in the desiccation, reworking and erosion of sediments that would have contained any evidence of a shift towards C_4 plants, with the possible exception of the data from the period just prior to 4 000 B.P. While no evidence of such processes could be definitively identified within the core, this may be a limitation of the small sample size, both in the size and number of cores.

6.4 Correlation with Previously Excavated Material

Attempting to correlate these paleoenvironmental and paleoclimatic results with the previously excavated material from the 1988 and 1989 field seasons, while not impossible, cannot be achieved with any level of precision. Horizontal differences between the two cores, which were taken about 4 m from one another, show considerable variations in the nature and thickness of the deposits across relatively small distances (Figure 5.1 and 5.2). These variations, in turn, suggest that it is not appropriate to attempt to directly correlate each occupation layer identified by Ramsay during his excavation with the stratigraphic record provided by the cores. The cores were taken downslope from where the original excavation took place. Given the variable topography of the site's hillslope location, significant variation in the sedimentary record would be expected between the original excavation records and the core descriptions.

Table 6.1 shows the results of the radiocarbon dating that took place during Ramsay's study of the excavation (1993: 90, 94), as well as an additional date obtained during Burt's 1997 study of landscape evolution of sites within Wanuskewin Heritage Park (Burt 1997). The radiocarbon date obtained during the present study is also presented in Table 6.1. Despite potential problems with bulk soil organic matter radiocarbon dating, this date correlates well with both the approximate depths and sequence of dates from the other two studies. It is reasonable to conclude that the newest addition to this suite of dates can be associated with cultural level 13, which encompasses dates both prior and subsequent to the present date and occurs at a comparable depth below surface.

Table 6.1. Approximate depth, cultural layer association and radiocarbon date from samples taken during the original excavation (Ramsay 1993: 90), subsequent geomorphological study (Burt 1997: 145), and the present study of the Red Tail site. Depths listed from the original excavation are those described in a stratigraphic column rather than the depths of the actual samples as this information was not recorded in the thesis (Burt 1997: 145).

Sample Number	**Depth (m)**	**Cultural Level (Sublayer)**	**RC Date (yrs B.P.)**
TO-5764 (Burt)	0.89	9 (?)	3100 ± 80
S-3372 (Ramsay)	1.1 – 1.12	11	3480 ± 80
S-3373 (Ramsay)	1.14 – 1.16	12 (1)	3470 ± 80
S-3008 (Ramsay)	1.14 – 1.16	12 (2)	3660 ± 75
S-3374 (Ramsay)	1.18 – 1.23	13 (2)	3860 ± 70
S-3375 (Ramsay)	1.18 -1.23	13 (2)	3880 ± 70
WNS-RT-05-02 20-22 cm	1.34 – 1.36	13 (?)	3990 ± 30
S-3009 (Ramsay)	1.27 – 1.34	13 (4)	4280 ± 80
S-3007 (Ramsay)	2.02 – 2.05	15	5010 ± 90

Ramsay's cultural level 13 is associated with the McKean Complex based on diagnostic artifacts found within the level (1993: 49). Figure 6.2 illustrates the stratigraphy of the site from a profile drawing produced during the original excavation. Due to the large exposure, more subtle variations in stratigraphy can be identified than within the small diameter of a Geoprobe core. While Ramsay was able to identify slight differentiations between occupation levels, far fewer stable land surfaces were identified within the core stratigraphy. This could be a result of compaction of levels within the core or it could be a result of horizontal differences between the original excavation site and the location further downslope where the cores were recovered.

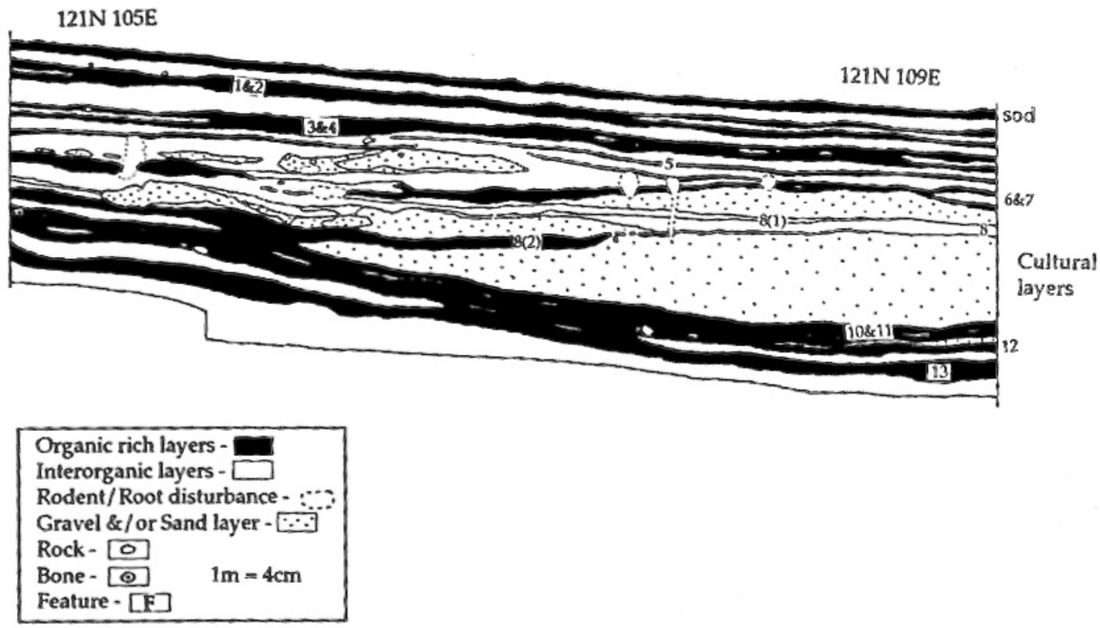


Figure 6.2. Profile drawing from original excavation of the Red Tail site of the north wall of the Upper Block, 121N 105E to 121N 109E (Ramsay 1993: 71).

While the purpose of this study is not to examine the McKean Complex, one of the objectives is to provide paleoenvironmental and paleoclimatic context for the previously excavated archaeological material at the Red Tail site. The correlation of the results of the present study with the history of occupation at the Red Tail site demonstrates the type of environment within which groups of people were living. The possible period of warmer, drier conditions just prior to 4 000 B.P. is located below any of the culture bearing layers identified by Ramsay during the original excavations. The McKean population, along with all other inhabitants of the Red Tail site, would have experienced a cool, moist climate and an environment rich with C_3 plant species.

6.5 Summary

Following deglaciation, the area that would eventually be home to the Red Tail site saw high levels of geomorphic activity. The sediment record found within the cores includes evidence of a number of different depositional environments of varying energies. A number of questions as to the depositional environment remain, including the possibility of sediments from the Hypsithermal being absent from or unidentified in the record. Stable carbon isotope and phytolith analysis have proven to be effective methods for paleoenvironmental and paleoclimatic study in the area. Both lines of evidence correlate well and demonstrate a fairly consistent history of C_3-dominated vegetation at the site during the latter part of the Holocene in particular. Evidence of a subtle shift exists just prior to 4 000 B.P., with a slightly decreased percentage of C_3 vegetation evident in the stable carbon isotope data and a slight increase in the relative percentage of Panicoid and Chloridoid phytoliths. These results provide paleoenvironmental and paleoclimatic context for the previously excavated archaeological material, correlation that is made possible by the radiocarbon date.

Chapter 7: Summary and Conclusions

7.1 Introduction

The goals of this research centered around three main objectives:

1) To determine the geomorphic history of the immediate area of the Red Tail site through analysis of soil and sediment recovered in two Geoprobe cores;

2) To determine if stable isotope analysis and phytolith analysis of soils and sediments are feasible and successful methods for paleoenvironmental reconstruction at the Red Tail site and by implication have potential application to other sites in Wanuskewin Heritage Park;

3) To provide paleoenvironmental context for archaeological research in Wanuskewin Heritage Park specifically and the Northern Plains more generally through a combination of laboratory methods, including description of soil and sediment in the cores, as well as stable carbon isotope analysis and phytolith analysis.

The research process began by taking several cores from the Red Tail site in Wanuskewin Heritage Park. The method of extraction used for the cores was the Geoprobe coring rig, which recovered a column of soils and sediments to a depth of approximately 6.5 m. This allowed for the investigation of sediments from much greater depths than were exposed during excavation of the Red Tail site in 1988 to 1989. Two of the cores were then analyzed using descriptive logging, particle size analysis, carbon content analysis, stable carbon isotope analysis, and phytolith analysis.

The descriptive logging process included photographing, identifying, measuring and recording sediments and possible buried soils in the cores selected for study. This description of the sediment/soil attributes included colour, soil and sediment structure, upper and lower boundaries, mottling and inclusions and texture by feel. The soils and sediments were then further analyzed through automated particle size analysis and automated carbon content analysis. Samples from one of the cores, WNS-RT-05, were submitted for stable carbon isotope analysis, which was done at the University of Calgary. Phytolith extraction and analysis was completed on samples from the same core in order to identify and classify short-cell phytoliths based on the methods of Fredlund and Tieszen (1994). Radiocarbon dating was also performed on organic sediment in two sediment samples from the same core in order to provide chronological control.

7.2 Geomorphic Summary and Conclusions

The first objective of this research, to determine the geomorphic history of the immediate site area as best as possible given the narrow columns of soil and sediments recovered by the Geoprobe, was achieved through analysis of soil and sediment in the two cores selected for study. This work was done in conjunction with a review of previous archaeological and geomorphic research at the site and within Wanuskewin Heritage Park, as well as investigation of the site's surficial geomorphology through air and satellite photos and surface inspection. The present study provided geomorphic data from depths beyond those reached by the original archaeological excavation, revealing an extended depositional history of glaciolacustrine, alluvial and colluvial processes.

The record of sediment deposition begins with thick clay deposits found from approximately 5.7 m to 6.5 m below surface in core WNS-RT-05, which was the more intensively analyzed of the two cores. These deposits are indicative of a glaciolacustrine environment consistent with the presence of a Late Pleistocene glacial lake in the area. As deglaciation continued and the glacial lake began to drain, the cores show significant alluvial deposition of mostly sandy sediments from approximately 5.7 m to 3.5 m below surface, with a lack of soil development that would indicate intervals of landscape stability. The soil and sediment extending from 3.5 m below surface to the top of the cores, combined with data from earlier studies at the site, indicate a much less depositionally active environment during the latter half of the Holocene. A fining upward sequence appears at approximately 3.5 m below surface, indicating a period of decreasing depositional energy that may reflect an episode of flood-related overbank deposition. This is followed by a long segment of sandy sediments that most likely reflects a continued pattern of alluvial and possibly aeolian processes persisting at the site. A sequence of buried A-horizons appears in WNS-RT-05, indicating enough periodic landscape stability to allow the establishment of plant communities and soil development. The short duration of these stable episodes is evidenced by the fact that these A-horizons represent Regosols whose formation was terminated when they were buried by periods of alluvial and colluvial deposition. This pattern is ideal for preservation of archaeological material and paleoenvironmental evidence and makes the context opportune for an integrated study of the area's history of human occupation, climate and environment.

7.3 Success of Study Methods

The second goal of this research was to determine if stable carbon isotope and phytolith analysis were useful proxy indicators of paleoenvironmental conditions during the period represented by the soils and sediments in the cores from the Red Tail site. Simply put, the answer to this research question is yes. The samples from buried A-horizons provided stable carbon isotope and phytolith data, and these, in turn, proved useful for characterizing the climate and vegetation in the area during the Holocene. Furthermore, the geomorphic reconstruction determined through descriptive logging provided complementary data on the landform processes at the site, offering additional information on the climate and vegetation conditions that might have been associated with these processes. This combination of methods has provided an opportunity for paleoenvironmental reconstruction at the Red Tail site and the immediately surrounding area. There are some limitations in regard to the geographical extent of these paleoenvironmental conclusions, as stable isotope analysis and phytolith analysis reflect the vegetation communities that produced the buried soils at and around the site, rather than conditions across the greater region. Still, these conclusions contribute to our understanding of the environment that past human groups encountered in the area that is now Wanuskewin.

7.4 Paleoenvironment Summary and Conclusions

The final goal of this study was to provide paleoenvironmental context using those proxy indicators, not only for the previously excavated material at the Red Tail site, but also for Wanuskewin Heritage Park as a whole, thus also contributing to what is known about the paleoenvironment and paleoclimate of the Northern Plains. This site provided a prime opportunity to investigate past climate in the context of a previously excavated archaeological site.

The complementary proxy data produced though stable carbon isotope and phytolith analysis demonstrate a fairly consistent history of C_3 plant and Pooid grass dominance at the Red Tail site. There is a slight, but important, deflection just prior to the radiocarbon date of 4000 +/- 30 B.P.; at this point the percentage of C_3 plants drops to approximately 70%, and the relative percentage of Chloridoid and Panicoid phytoliths increases. This slight shift in vegetation may demonstrate a slight climate change at the site, during what would have most likely been the end of the Hypsithermal. Following this, a shift to cooler, moister conditions is reflected in consistently high percentages of C_3-plant-dominated communities and an abundance of Pooid phytoliths.

These results are significant in that they provide paleoenvironmental and paleoclimatic context for the previously excavated archaeological material at the Red Tail site. Human populations inhabiting the Red Tail site would experienced relatively cool, moist climate conditions and these conditions appear to have been relatively consistent over the period in which the site shows evidence of human occupation. As noted above, these results primarily reflect conditions in the park, leaving further questions about the conditions in the wider region. However, the consistent presence of a well-watered environment that likely supported abundant vegetation may have been part of what kept drawing precontact human groups back to the site and the area of the park.

7.5 Areas for Future Research

While the conclusions of this study fully satisfy the stated objectives, they also identify areas that would greatly benefit from further exploration. Certainly there would be considerable benefit in repeating the study methods with additional cores from a variety of locations along the Opiminhaw Creek and South Saskatchewan River Valleys. The study methods were successful in providing proxy paleoenvironmental data, although these data are most reflective of conditions in the immediate site and park area. Therefore their repeated use in additional locations would help build a more complete record of paleoenvironment and paleoclimate in these archaeologically rich valleys. Preservation of sediments may also be different at other site locations within the valleys, offering opportunities to develop a more complete record through the earlier portion of the Holocene.

A prime example of what archaeologists might hope to find to contribute more fully to our understanding of human and environmental interaction during the Hypstithermal is the St. Louis site (Cyr et al. 2011). The St. Louis' site is a multi-component site located within the South Saskatchewan River Valley with material dating to the Late Paleoindian to Middle Precontact periods (10 000–5 000 ^{14}C yr B.P.) (Cyr et al. 2011). The comprehensive record of sediments and archaeological material make this site an important example of a context in which the Early to Middle Precontact period can be more fully understood archaeologically and paleoenvironmentally. The Early to Middle Precontact is a period from which no buried soils appeared in the Red Tail cores, but one that is important for understanding human interaction during the climatic variability of the Hypsithermal.

At several points, the sample size recovered during coring has been a limiting factor in the interpretation of geomorphic evidence. While Geoprobe coring offers the opportunity to quickly and easily recover lengthy sections of subsurface sample with very little disruption to the coring site, a larger exposure would be beneficial for interpreting geomorphic information that may not be readily identifiable in the narrow columns provided by Geoprobe cores. Examples of such would be the identification of the topography of upper and lower boundaries or flame structures. A larger exposure of the stratigraphic profile may aid in the geomorphic interpretation within the area, but such exposures also have their disadvantages including: safety and cost of excavation, difficulty in reaching depths as great as those reached by cores and the destruction of archaeological deposits in a culturally sensitive landscape.

The phytolith analysis conducted in this study is concerned mostly with the grass phytoliths that have been well documented across the Great Plains and which are currently a major component of the mixed grassland vegetation found in and around the site area. While this has proven to be a successful research method in this grass-rich area, there are also other forms of C_3 plants that could be contributing to the record of consistently C_3-dominated vegetation at the site. This is especially important given the area's close proximity to the boundary between the mixed grassland and aspen parkland ecozones. An attempt at considering the contribution of these non-grass C_3 plants was made in calculating the ratio of non-short-cell phytoliths found within the samples against the numbers of short-cell phytoliths recovered (Figure 5.12). This certainly demonstrates a potential area for further research. A dedicated phytolith research study in which a comparative collective was created to document the specific array of mixed grassland and parkland species found in central Saskatchewan would benefit the understanding of how non-grass C_3 plants contributed to the vegetative history of the site by allowing future researchers to expand the array of phytoliths that they can identify in core samples. There is a paucity of information on non-short-cell phytoliths on the Northern Plains, further demonstrating the need for the expansion of the type of research that was initiated in Bozarth 1993, but not further developed.

It has been suggested that Wanuskewin Heritage Park may represent an "island on the prairie". For example, Smith describes the park "as a terrestrial island that exerted a pull on the occupants of the plains thereby shaping their behavior in relation to subsistence, settlement and mobility decisions" (Smith 2012: 205). There are a number of lines of evidence to be considered in this theory, but certainly the climate and environment would have been a factor that influenced how humans moved across the landscape and interacted with their environment. In order to more fully understand the big picture of how humans interacted with their environment in this landscape, it is important to look outside the area identified as an oasis. While the Red Tail site shows evidence of fairly consistently cool, moist climate, the surrounding area may have experienced considerably harsher climate conditions, both during the Hypsithermal and during drought periods of smaller duration and magnitude. If this is the case, that would certainly contribute to the pull this area exerted on the groups moving across the Plains. In order to further explore this line of questioning, paleoenvironmental research should be expanded outside the Park boundaries. The present study gives important information on the more immediate area, but the land beyond that also holds invaluable information on why human groups chose to so heavily occupy the area now known as Wanuskewin Heritage Park.

Works Cited

Acton, D.F., G.A. Padbury, and C.T. Stushnoff
1998 *The Ecoregions of Saskatchewan.* Canadian Plains Research Center, Regina.

Alam, A.K.M.M., S. Xie and L.A. Wallis
2009 Constructing Late Holocene Palaeoenvironments in Bangladesh: Phytolith Analysis of Archaeological Soils from Somapura Mahavihara Site in the Paharpur Area, Badalgacchi Upazila, Naogaon District, Bangladesh. *Journal of Archaeological Science* 36: 504-512.

Ambrose, S.H. and N.E. Sikes
1991 Soil Carbon Isotope Evidence for Holocene Change in the Kenya Rift Valley. *Science* 253: 1402-1405.

Anderson, D.E., A.S. Goudie, and A.G. Parker
2007 *Global Environments through the Quaternary: Exploring Environmental Change.* Oxford University Press, New York.

Anderson, T.W., R.W. Mathewes, and C.E. Schweger
1989 Holocene Climatic Trends in Canada with Special Reference to the Hypsithermal Interval. In *Quaternary Geology of Canada and Greenland,* edited by R.J. Fulton, pp. 520-528. Geological Survey of Canada Geology of Canada No. 1. Geological Survey of Canada, Ottawa.

Antevs, E.
1955 Geologic-Climatic Dating in the West. *American Antiquity* 20: 317-335.

Artz, J.A.
1996 Cultural Response or Geological Process? A Comment on Sheehan. *Plains Anthropologist* 41: 383-393.

Atlas of Saskatchewan
1999 Map of Snowfall. In *Atlas of Saskatchewan*, edited by K. Fung, B. Barry, and M. Wilson, pp.106. University of Saskatchewan, Saskatoon.

Banfield, A.W.F.
1974 *The Mammals of Canada.* University of Toronto Press, Toronto.

Barnosky, C.W., E.C. Grimm and H.E. Wright Jr.
1987 Towards a Postglacial History of the Northern Great Plains: A Review of the Paleoecologic Problems. *Annals of the Carnegie Museum* 56: 259-273.

Beaty, C.B.
1972 The Effect of Moisture on Slope Stability: A Classic Example from Southern Alberta, Canada. *The Journal of Geology* 80: 362-366.

Beaudoin, A.B.
1993 A Compendium and Evaluation of Postglacial Pollen Records in Alberta. *Canadian Journal of Archaeology* 17: 92-112.

Bekele, A. and W.H. Hudnall
2003 Stable Carbon Isotope Study of the Prairie-Forest Transition Soil in Louisiana. *Soil Science* 168: 383-390.

Berglund, B. and T. Persson
2004 Information on Spore Tablets. Electronic Document, http://www.geo.arizona.edu/palynology/LY483216.PDF. Accessed April 25, 2013.

Bettis III, E. A.
1992 Soil Morphologic Properties and Weathering Zone Characteristics as Age Indicators in Holocene Alluvium in the Upper Midwest. In *Soils in Archaeology: Landscape Evolution and Human Occupation,* edited by V. T. Holliday, pp. 119-144. Smithsonian Institution, Washington.

Bettis, A. E. III, A. K. Milius, S.J. Carpenter, R. Larick, Y. Zaim, Y. Rizal, R. L. Ciochon, S.A. Tassier-Surine, D. Murray, Suminto, and S. Bronto.
2009 Way Out of Africa: Early Pleistocene Paleoenvironment Inhabited by Homo erectus in Sangaran, Java. *Journal of Human Evolution* 56: 11-24.

Biedendender, S.H. M.P. McClaran, J. Quade and M.A. Weltz
2004 Landscape Patterns of Vegetation Change Indicated by Soil Carbon Isotope Composition. *Geoderma* 119: 69-83.

Birkeland, P.W.
1999 *Soils and Geomorphology.* 3rd ed. Oxford University Press, New York.

Boutton, T.W., A.T. Harrison, and B.N. Smith
1980 Distribution of Biomass of Species Differing in Photosynthetic Pathway along an Altitudinal Transect in Southeastern Wyoming Grassland. *Oecologia* 45: 287-298.

Boutton, T.W. S.R. Archer, and L.C. Nordt
1994 Climate, CO_2 and Plant Abundance. *Nature* 372: 625-626.

Boyd, M.
2005 Phytoliths as Paleoenvironmental Indicators in a Dune Field on the Northern Great Plains. *Journal of Arid Environments* 61: 357-375.

Bozarth, S.
1993 Biosilicate Assemblages of Boreal Forests and Aspen Parklands. In *Current Research in Phytolith Analysis: Applications in Archaeology and Paleoecology,* edited by D.M. Pearsall and D.R. Piperno, pp. 95-105. MASCA Research Papers in Science and Archaeology Vol 10. The University Museum of Archaeology and Anthropology, University of Pennsylvania, Philadelphia.

Bradley, R.S. and P.D. Jones
1995 Recent Developments in Studies of Climate since A.D. 1500. In *Climate Since A.D. 1500*, Revised Edition, edited by R.S. Bradley and P.D. Jones, pp. 666-680. Routledge, London.

Brady, N.C. and R.R. Weil
2002 *The Nature and Properties of Soils*. 13th ed. Prentice Hall, New Jersey.

Brown, D.
1984 Prospects and Limits of a Phytolith Key for Grasses in the Central US. *Journal of Archaeological Science* 11: 345-368.

Bryan, L.
2005 *The Buffalo People: Pre-contact Archaeology on the Canadian Plains*. Heritage House Publishing Company Ltd., Surrey, British Columbia.

Buchner, A.P.
1980 *Cultural Responses to the Altithermal Climate Along the Eastern Margins of the North American Grasslands: 5,500 to 3,000 B.C.* Mercury Series Paper 97. National Museum of Man, Ottawa.

Burt, A.K.
1997 Landscape Evolution at Wanuskewin Heritage Park, Saskatoon, Saskatchewan. Unpublished Masters Thesis, Department of Geography, University of Saskatchewan, Saskatoon.

Carbone, V.A.
1977 Phytoliths as Paleoecological Indicators. *Annals of the New York Academy of Sciences* 288: 194-205.

Cerling, T.E., J.A. Quade, S.H. Ambrose, and N.E. Sikes
1991 Fossil Soils, Grasses and Carbon Isotopes from Fort Ternan, Kenya: Grassland or Woodland? *Journal of Human Evolution* 21: 295-306.

Cerling, T.E., J.A. Quade, Y. Wang and J.R. Bowman
1989 Carbon Isotopes in Soils and Paleosols as Ecology and Paleoecology Indicators. *Nature* 341: 138-139.

Childe, V.G.
1969 *Prehistoric Migrations in Europe.* Anthropological Publications, Netherlands.

Christiansen, E.A.
1968 Pleistocene Stratigraphy of the Saskatoon Area, Saskatchewan, Canada. *Canadian Journal of Earth Sciences* 5: 1167-1173.

1970 Geology. In *Physical Environment of Saskatoon, Canada,* edited by E.A. Christiansen, pp. 3-18. Saskatchewan Research Council in co-operation with the National Research Council of Canada, Ottawa.

1979a The Wisconsinan Deglaciation of Southern Saskatchewan and Adjacent Areas. *Canadian Journal of Earth Sciences* 16: 913-938.

1979b *Geology of the Saskatoon Region, Saskatchewan.* E. A. Christiansen Consulting Ltd. Saskatchewan Municipal Affairs, Regina.

1992 Pleistocene Stratigraphy of the Saskatoon Area, Saskatchewan, Canada: An Update. *Canadian Journal of Earth Sciences* 29: 1767-1778.

Christiansen E.A. and E.K. Sauer
1998 Geotechnique of Saskatoon and Surrounding Area, Saskatchewan, Canada. In *Urban Geology of Canadian Cities,* edited by P.F. Karrow and O.L. White, pp.117-145. Geological Association of Canada Special Paper 42. Geological Association of Canada, St. John's.

Clifton Associates Ltd.
1985 *Slope Instability Study, South Saskatchewan River Banks, Saskatoon, Saskatchewan.* Meewasin Valley Authority, Saskatoon.

Courty, M.A., P. Goldberg and R. Macphail
1989 *Soils and Micromorphology in Archaeology.* Cambridge University Press, New York.

Cyr, T.
2006 The Dog Child Site (FbNp-24): A 5500 Year-Old Multicomponent Site on the Northern Plains. Unpublished Masters Thesis, Department of Anthropology and Archaeology, University of Saskatchewan, Saskatoon.

Cyr, H., C. McNamee, L. Amundson, and A. Freeman
2011 Reconstructing Landscape and Vegetation Through Multiple Proxy Indicators: A Geoarchaeological Examination of the St. Louis Site, Saskatchewan, Canada. *Geoarchaeology: An International Journal* 26: 165-188.

Dawson, T.E., S. Mambelli, A.H. Plamboeck, P.H. Templer, and K.P. Tu
2002 Stable Isotopes in Plant Ecology. *Annual Review of Ecology and Systematics* 33: 507-559.

de Frietas, H.A. L.C. Ruiz Pessenda, R. Aravena, S.E. Marques Gouveia, A. de Souza Ribeiro and R. Boulet
2001 Late Quaternary Vegetation Dynamics in Southern Amazon Basin Inferred from Carbon Isotopes in Soil Organic Matter. *Quaternary Research* 55: 39-41.

Deevey, E.S. and R.F. Flint
1957 Postglacial Hypsithermal Interval. *Science* 125: 182-184.

DeNiro, M.J.
1987 Stable Isotopy and Archaeology. *American Scientist* 75: 182-191.

Domaar, J.F. and L.E. Lutwick
1969 Infrared Spectra of Humic Acids and Opal Phytoliths as Indicators of Paleosols. *Canadian Journal of Soil Science* 86: 29-37.

Dyck, I.
1983 The Prehistory of Southern Saskatchewan. In *Tracking Ancient Hunters, Prehistoric Archaeology in Saskatchewan*, edited by H.T. Epp and I. Dyck, Saskatchewan Archaeological Society, Regina.

Environment Canada
2010a Hydrology of Canada. Electronic document, http://www.ec.gc.ca/rhc-wsc/default.asp?lang=En&n=E94719C8-1, accessed November 19, 2012.

2010b National Climate Data and Information Archive. Electronic document, http://www.climate.weatheroffice.gc.ca/Welcome_e.html, accessed February 7, 2011.

Expert Committee on Soil Survey
1982 The Canada Soil Information System (CanSIS): Manual for Describing Soils in the Field, 1982 Revised. Land Resource Research Institute, Research Branch, Agriculture Canada, Ottawa. LRRI Contribution no 82-52. 166 pp.

Feggestad, A.J., P.M. Jacobs, X. Miao and J.A. Mason
2004 Stable Carbon Isotope Record of Holocene Environmental Change in the Central Great Plains. *Physical Geography* 25: 170-190.

Fenton, M.M.
1984 Quaternary Stratigraphy of the Canadian Prairies. In *Quaternary Stratigraphy of Canada - A Canadian Contribution to IGCP Project 24*, edited by R.J. Fulton, pp. 57-68. Geological Survey of Canada, Ottawa.

Fenton, M.M., B.T. Schreiner, E. Nielsen, and J.G. Pawlowicz
1994 Quaternary Geology of the Western Plains. In *Geological Atlas of the Western Canada Sedimentary Basin*, compiled by Grant Mossop and Irina Shetsen. Electronic document, http://www.ags.gov.ab.ca/publications/wcsb_atlas/a_ch26/ch_26.html, accessed November 22, 2012.

Frary, H.E.
2009 The Meewasin Creek Site (FbNp-9): A Re-examination of the Terminal Middle Precontact Period. Unpublished Masters Thesis, Department of Anthropology and Archaeology, University of Saskatchewan, Saskatoon.

Fredlund, G.G., C.B. Bousman and D.K. Boyd
1998 The Holocene Phytolith Record from Morgan Playa in the Rolling Plains of Texas. *Plains Anthropologist* 43: 187-200.

Fredlund, G.G. and Tieszen, L.L.
1994 Modern Phytolith Assemblages from the North American Great Plains. *Journal of Biogeography* 21: 321-335.

1997 Phytolith and Carbon Isotope Evidence for Late Quaternary Vegetation and Climate Change in the Southern Black Hills, South Dakota. *Quaternary Research* 47: 206-217.

Frison, G. C.
1978 *Prehistoric Hunters of the High Plains.* Academic Press, New York.

1991 *Prehistoric Hunters of the High Plains*, 2nd edition. Academic Press, San Diego.

1998 The Northwestern and Northern Plains Archaic. In *Archaeology on the Great Plains,* edited by Raymond W. Wood, pp. 140-172. University Press of Kansas, Lawrence.

2004 *Survival By Hunting: Prehistoric Human Predators and Animal Prey*. University of California Press, Berkeley.

Frison, G.C. and M.H. Huseas
1968 Leigh Cave, Wyoming, Site 48WA304. *The Wyoming Archaeologist* 11: 20-33.

Gerrard, J.
2000 *Fundamentals of Soils.* Routledge, London.

Gibbon, G.G. and K.M. Ames
1998 *Archaeology of Prehistoric Native America: An Encyclopedia.* Garland Publishing, New York.

Gilbert, B.M.
1980 The Plains Setting. In *Anthropology on the Great Plains,* edited by W. Raymond Wood and Margot Liberty, pp. 8-15. University of Nebraska Press, Lincoln.

Google Earth (Version 6.1.0.5001) [Software]
2009 Mountain View, CA: Google Inc. Available from http://www.google.com/earth/index.html.

Gray, A.B., G.B. Pasternack and E.B. Watson
2010 Hydrogen Peroxide Treatment Effects on the Particle Size Distribution of Alluvial and Marsh Sediments. *The Holocene* 20: 293-301.

Gross, J.
2011 Introduction. In *Mass Spectrometry: A Textbook*, 2nd ed., edited by J. Gross, pp. 1-20. Springer-Verlag, Berlin.

Grove, J.M.
2003 *The Little Ice Age*. Routledge. eBook Collection (EBSCOhost), accessed via University of Saskatchewan Library web page, accessed January 15, 2013.

Gryba, E.
1980 Early Side-Notched Point Tradition in the Central and Northern Plains. In *Directions in Manitoba Prehistory*. Archaeological Society of Manitoba, Winnipeg.

Harland, W.B., R.L Armstrong, A.V. Cox, L.E. Craig, A.G. Smith, and D.G. Smith
1990 *A Geologic Time Scale*. 1989 edition. Cambridge University Press, Cambridge.

Herz, N.
1990 Stable Isotope Geochemistry Applied to Archaeology. In *Archaeological Geology of North America*, edited by N.P. Lasca and J. Donahue, pp. 585-595. Geological Society of America, Centennial Special Volume 4, Boulder, Colorado.

Hohmann-Marriott, M.F. and R.E. Blankenship
2012 The Photosynthetic World. In *Photosynthesis: Plastid Biology, Energy Conservation and Carbon Assimilation, Advances in Photosynthesis and Respiration,* edited by J.J. Eaton-Rye, B.C. Tripathy, and T.D. Sharkey, pp. 3-32. Springer, New York.

Holliday, V.
2004 *Soils in Archaeological Research*. Oxford University Press, New York.

Hurt Jr., W.R.
1966 The Altithermal and the Prehistory of the Northern Plains. *Quaternaria* 8: 101–113.

Husted, W.M.
1969 *Bighorn Canyon Archaeology*. Smithsonian Institution River Basin Surveys, Publications in Salvage Archaeology No. 12. Lincoln, Nebraska.

2002 Archaeology in the Middle Rocky Mountains: Myopia, Misconceptions and Other Concerns. *Plains Anthropologist* 47: 379-386.

Jahn, R., H.P. Blume, V.B. Asio, O. Spaargaren, and P. Schad
2006 *Guidelines for Soil Description.* 4th ed. Food and Agriculture Organization of the United Nations, Rome.

Jennings, J.D.
1957 Danger Cave. University of Utah, Anthropological Papers 27. University of Utah Press, Salt Lake City.

Kehew, A.E. and J.T. Teller
1994 History of Late Glacial Runoff Along the Southwestern Margin of the Laurentide Ice Sheet. *Quaternary Science Reviews* 13: 859-877.

Kelly, E.F., C. Yonker and B. Marino.
1993 Stable Carbon Isotope Composition of Paleosols: An Application to Holocene. In *Climate Change in Continental Isotopic Records,* edited by P.K. Smart, K.C. Lohmann, J. McKenzie and S. Savin, pp. 233-239. Geophysical Monograph 78. American Geophysical Union, Washington, D.C.

Kelly, E.F., S.W. Blecker, C.M. Yonker, C.G. Olson, E.E. Wohl, L.C. Todd
1998 Stable Isotope Composition of Soil Organic Matter and Phytoliths as Paleoevironmental Indicators. *Geoderma* 82: 59-81.

Keyser, J.D. and C.M. Davis
1985 Lightning Spring and Red Fox: McKean Research in the Grand River Drainage. In *McKean/Middle Plains Archaic: Current Research, Occasional Papers on Wyoming Archaeology Number* 4, edited by M. Kornfeld and L.C. Todd, pp. 123-136. Wyoming Recreation Commission, Cheyenne.

Klassen, R.W.
1989 Quaternary Geology of the Southern Canadian Interior Plains. In *Quaternary Geology of Canada and Greenland*, edited by R.J. Fulton, pp. 138-174. Geological Survey of Canada, Ottawa.

Kooyman, B.
2000 *Understanding Stone Tools and Archaeological Sites*. University of Calgary Press, Calgary.

Koper, N., K.E. Mozel and D.C. Henderson
2010 Recent Declines in Northern Tall-Grass Prairies and Effects of Patch Structure on Community Persistence. *Biological Conservation* 143: 220-229.

Kornfeld, M., G.C. Frison, and M.L. Larson
2010 *Prehistoric Hunters of the High Plains.* 3rd ed. Academic Press, New York.

Laird, K.R., B.F. Cumming, S. Wunsam, J.A. Rusak, R.J. Oglesby, S.C. Fritz, and P.R. Leavitt
2003 Lake Sediments Record Large-Scale Shifts in Moisture Regimes Across the Northern Prairies of North America During the Past Two Millennia. *Proceedings of the National Academy of Sciences of the United States of America* 100: 2483-2488.

Lamers, L.
1988 *Flood Frequencies in the South Saskatchewan River Basin.* Saskatchewan Water Corporation, Moose Jaw.

Lamoureux, S.F. and J.M.H. Cockburn
2005 Timing and Climatic Controls over Neoglacial Expansion in the Northern Coast Mountains, British Columbia, Canada. *Holocene* 15: 619-624.

Landi, A., A.R. Mermut and D.W. Anderson
2004 Carbon Distribution in Hummocky Landscape from Saskatchewan, Canada. *Soil Science Society of America Journal* 68: 175-184.

Landi, A., D.W. Anderson and A.R. Mermut
2003a Organic Carbon Storage and Stable Isotope Composition of Soils along a Grassland to Forest Environmental Gradient in Saskatchewan. *Canadian Journal of Soil Science* 83: 405-414.

2003b Origin and Rate of Pedogenic Carbonate Accumulation in Saskatchewan Soils, Canada. *Geoderma* 117: 143-156.

Last, W.M.
1990 Paleochemistry and Paleohydrology of Ceylon Lake, a Salt-Dominated Playa Basin in the Northern Great Plains, Canada. *Journal of Paleolimnology* 4: 219-238.

Last, W.M. and R.E. Vance
2002 The Holocene History of Oro Lake, One of the Western Canada's Longest Continuous Lacustrine Records. *Sedimentary Geology* 148: 161-184.

LECO Corporation
2012 SC632: Sulfur and Carbon in Organic Samples. Electronic document, http://www.leco.com/products/organic/sc632/SC632.html, accessed May 10, 2012.

Lemmen, D. and R.E.Vance
1998 Climatic Variability on the Southern Canadian Prairies during the last 1000 years based on Multiple Proxy Indicators. In *Decoding Canada's Environmental Past: Climate Variations and Biodiversity Change during the last Millennium*, edited by Don C. MacIver and Rebecca E. Meyer, pp. 45-51. Environment Canada, Downsview, Ontario.

Linnamae, U., E.G. Walker, and D.L. Kelly
1988 A Summary of the Archaeology of the Saskatoon Area. In *Out of the Past: Sites, Digs and Artifacts in the Saskatoon Area,* edited by Urve Linnamae and Tim E. H. Jones, pp. 155-171. Saskatoon Archaeological Society, Saskatoon.

Lowe, J.J. and M.J.C. Walker
1997 *Reconstructing Quaternary Environments*. Addison Wesley Longman Limited, Essex.

Maathuis, H.
1999 Groundwater in Southern Saskatchewan. In *Atlas of Saskatchewan*, edited by K. Fung, B. Barry, and M. Wilson, pp.106. University of Saskatchewan, Saskatoon.

MacDonald, G. M. and J. C. Ritchie
1986 Modern Pollen Spectra from the Western Interior of Canada and the Interpretation of Late Quaternary vegetation development. *New Phytologist* 103: 245-268.

Malvern Instruments Ltd.
2005 Mastersizer 2000: Integrated Systems for Particle Size Brochure. Electronic document, http://www.malvern.com/common/downloads/MRK501.pdf, accessed January 26, 2013.

2013 Mastersizer 2000. Electronic document, www.malvern.com/labeng/products/mastersizer/ms2000/mastersizer2000.htm, accessed January 26, 2013.

Mann, M.E.
2002 Little Ice Age. In *Encyclopedia of Global Environmental Change,* edited by M.C. MacCracken and J.S. Perry, pp. 504-509. John Wiley and Sons, Ltd., Chichester.

Maybank, J. and J.L. Bergsteinsson
1970 Climate of Saskatoon. In *Physical Environment of Saskatoon, Canada,* edited by E.A. Christiansen, pp. 22-38. Saskatchewan Research Council in co-operation with the National Research Council of Canada, Ottawa.

McKern, W.C.
1939 The Midwestern Taxonomic Method as an Aid to Archaeological Cultural Study. *American Antiquity* 4: 301-313.

McMillan, A.D. and E. Yellowhorn
2004 *First Peoples in Canada*. 3rd ed. Douglas & McIntyre, Vancouver.

Mermut, A.R. and A. Landi
2006 Secondary/Pedogenic Carbonates. In *Encyclopedia of Soil Science,* edited by Rattan Lal, pp. 1551-1554. Taylor and Francis, London, UK.

Mulloy, W.T.
1954 The McKean Site in Northeastern Wyoming. *Southwestern Journal of Anthropology* 10: 432-460.

1958 *A Preliminary Historical Outline for the Northwestern Plains*. University of Wyoming Publications in Science, Laramie.

Munsell ® Color
2000 Munsell ® Soil Color Charts. Revised Washable Edition. GretagMacbeth, New Windsor, New York.

Nelson, D.W. and L.E. Sommers
1982 Total Carbon, Organic Carbon and Organic Matter. In *Methods of Soil Analysis, Part 2: Chemical and Microbiological Properties*, 2nd ed., edited by A.L. Page, R.H. Miller, and D.R. Keeney, pp. 539-579. American Society of Agronomy and Soil Science Society of America, Madison, Wisconsin.

Neuman, R.W.
1975 *The Sonata Complex and Associated Sites on the Northern Great Plains*. Nebraska State Historical Society. Publications in Anthropology No. 5, Lincoln.

Nordt, L.C.
2001 Stable Carbon and Oxygen Isotopes in Soils: Applications for Archaeological Research. In *Earth Sciences and Archaeology,* edited by P. Goldberg, V.T. Holliday and C.R. Ferring, pp. 419-448. Kluwer Academic/Plenum Publishers, New York.

Nordt, L.C., T.W. Boutton, C.T. Hallmark and M.R. Waters
1994 Late Quaternary Vegetation and Climate Changes in Central Texas Based on the Isotopic Composition of Organic Carbon. *Quaternary Research* 41: 109-120.

Orlova, L.A. and V.A. Panychev
1993 The Reliability of Radiocarbon Dating Buried Soils. *Radiocarbon* 35: 369-377.

Partners FOR the Saskatchewan River Basin (PFSRB)
2009 From the Mountains to the Sea: The State of the Saskatchewan River Basin. www.saskriverbasin.ca/page.php?page_id=70

Pearsall, D.
2000 *Paleoethnobotany: A Handbook of Procedures.* Academic Press: London.

Peck, T.
2011 *Light from Ancient Campfire: Archaeological Evidence for Native Lifeways on the Northern Plains.* Athabasca University Press, Edmonton, AB.

Phillips, P. and G. R. Willey
1953 Method and Theory in American Archaeology: An Operational Basis for Culture-Historical Integration. *American Anthropologist* 55: 615-633.

Picard, M.D. and L.R. High Jr.
1973 *Sedimentary Structures of Ephemeral Streams.* Elsevier Scientific Publishing Co., Amsterdam.

Piperno, D.R.
1988 *Phytolith Analysis: An Archaeological and Geological Perspective.* Academic Press, Orlando.

2006 *Phytoliths: A Comprehensive Guide for Archaeologists and Paleoecologists.* Altamira Press: Oxford.

Pletz, J.R.
2010 Archaeological Investigations at The Dog Child Site (FbNp-24): An Evaluation of Mummy Cave Subsistence Patterns. Unpublished Masters Thesis, Department of Anthropology and Archaeology, University of Saskatchewan, Saskatoon

Porter, S.C., and G.H. Denton
1967 Chronology of Neoglaciation in the North American Cordillera. *American Journal of Science* 265: 177-210.

Porter, S.C., D.J. Sauchyn and L.D. Delorme
1999 The Ostracode Record from Harris Lake, Southwestern Saskatchewan: 9200 Years of Local Environmental Change. *Journal of Paleolimnology* 21: 35-44.

Prairie Adaptation Research Collaborative (PARC)
2013 Thunderstorms, Heavy Rainfall & Flooding. Electronic document, http://www.parc.ca/saskadapt/extreme-events/thunder-flood, accessed January 14, 2013.

Ramsay, C.L.
1993 The Redtail Site: A McKean Habitation in South Central Saskatchewan. Unpublished Masters Thesis, Department of Anthropology and Archaeology, University of Saskatchewan, Saskatoon.

Rapp, G. (Rip) and C.L. Hill
2006 *Geoarchaeology: The Earth-Science Approach to Archaeological Interpretation.* 2nd ed. Yale University Press, New Haven.

Reeves, B.O.K.
1973 The Concept of an Altithermal Cultural Hiatus in Northern Plains Prehistory. *American Anthropologist* 75: 1221-1253.

1983 Culture Change in the Northern Plains 1000 BC – AD 1000. Occasional Paper No. 20. Archaeological Survey of Alberta, Edmonton.

Robertson, E.C.
2006 *Late Quaternary Landform Development, Paleoenvironmental Reconstruction and Archaeological Site Formation in the Cypress Hills of Southeastern Alberta.* Ph.D. dissertation, Department of Archaeology, University of Calgary, Calgary, Alberta.

2011 Reassessing Hypsithermal Human-Environment Interaction on the Northern Plains. In *Human Interactions with the Geosphere*, edited by L. Wilson, pp. 181-194. Geological Society Special Publications 352. Geological Society of London, London.

Rovner, I.
1983 Plant Opal Phytolith Analysis: Major Advances in Archaeobotanical Research. In *Advances in Archaeological Method and Theory,* vol. 6*,* edited by M.B. Schiffer, pp. 225-266. Academic Press, New York.

Rutherford, J.S.
2004 Hillslope Sediments and Landscape Evolution in Wanuskewin Heritage Park: A Geoarchaeological Interpretation. Unpublished Masters Thesis, Department of Archaeology, University of Saskatchewan, Saskatoon.

Sambrook Smith, G.H., P.J. Ashworth, J.L. Best, J. Woodwards, and C.J. Simpson
2006 The Alluvial Architecture and Sedimentology of the Sandy, Braided South Saskatchewan River, Canada. *Sedimentology* 53: 413-434.

Saskatchewan Archives Board
2011 Saskatchewan Homestead Index Database. Electronic document, http://sab.minisisinc.com/sabmin/scripts/mwimain.dll/144/HOMESTEADS?DIRECTSEARCH, accessed May 28, 2013.

Sask Herbarium
2012 Ecoregions of Saskatchewan. Electronic document, http://www.usask.ca/biology/rareplants_sk/root/htm/en/researcher/4_ecoreg.php, accessed November 19, 2012.

Saskatchewan Land Resource Centre, University of Saskatchewan
1999 Dominant Soils. In *Atlas of Saskatchewan*, edited by K. Fung, B. Barry, and M. Wilson, pp.106. University of Saskatchewan, Saskatoon.

Sauchyn, D.J.
1990 A Reconstruction of Holocene Geomorphology and Climate, Western Cypress Hills, Alberta and Saskatchewan. *Canadian Journal of Earth Sciences* 27: 1504-1510.

Sauchyn, D.J. and A.B. Beaudoin
1998 Recent Climate Change in the Southwestern Canadian Plains. *The Canadian Geographer* 42: 337-353.

Sauchyn, D.J. and M.I. Vélez
2007 Holocene Climate Change. In *Saskatchewan: Geographic Perspectives*, edited by Bernard Thraves, pp. 57-62. Canadian Plains Research Centre, Regina.

Sauchyn, M.A. and D.J. Sauchyn
1991 A Continuous Record of Holocene Pollen from Harris Lake, Southwestern Saskatchewan, Canada. *Palaeogeography, Palaeoclimatology, Palaeoecology* 88: 13-23.

Schaetzl, R. and S. Anderson
2005 *Soils: Genesis and Geomorphology*. Cambridge University Press, Cambridge.

Scrimgeour, C.M. and D. Robinson
2004 Stable Isotope Analysis and Applications. In *Soil and Environmental Analysis: Modern Instrumental Techniques*, 3rd ed., edited by Keith A. Smith and Malcolm S. Cresser, pp. 381-431. Marcel Dekker, New York.

Selby, M.
1993 *Hillslope Materials and Processes*. 2nd ed. Oxford University Press, Oxford.

Sheehan, M.S.
1995 Cultural Responses to the Altithermal or Inadequate Sampling? *Plains Anthropologist* 40: 261-270.

Simpson, M.
1999 Quaternary Geology. In *Atlas of Saskatchewan*, edited by K. Fung, B. Barry, and M. Wilson, pp.106. University of Saskatchewan, Saskatoon.

Skwara, T.
1988 The Ice Age in the Saskatoon Area: Setting the Stage. In *Out of the Past: Sites, Digs and Artifacts in the Saskatoon Area,* edited by Urve Linnamae and Tim E. H. Jones, pp. 25-38. Saskatoon Archaeological Society, Saskatoon.

Skwara Woolf, T.
1980 *Mammals of the Riddell Local Fauna (Floral Formation, Pleistocene, Late Rancholabrean) Saskatoon, Canada.* Saskatchewan Culture and Youth, Museum of Natural History, Regina.

1981 Biostratigraphy and Paleoecology of Pleistocene Deposits (Riddell Member, Floral Formation, Late Rancholabrean), Saskatoon, Canada. *Canadian Journal of Earth Sciences* 18: 311-322.

Smith, N.
2012 Archaeological Investigations at the Cut Arm Site (FbNp-22): Evidence for Wanuskewin Heritage Park as an Island on the Plains. Unpublished Master's thesis. Department of Archaeology and Anthropology, University of Saskatchewan, Saskatoon.

Soil Classification Working Group
1998 *The Canadian System of Soil Classification.* 3rd ed. NRC Research Press, Ottawa.

Stafford, Jr. T.W.
1998 Radiocarbon Chronostratigraphy. In *Wilson-Leonard: An 11,000-Year Archaeoloigcal Record of Hunter-Gatherers in Central Texas, Vol. 5: Special Studies,* edited by M.B. Collins, pp. 1039-1066. Texas Archaeological Research Lab, University of Texas at Austin, Austin.

Summerfield, M.A.
1991 *Global Geomorphology.* Pearson Education Limited, Essex.

Syms, L.
1970 The McKean Complex in Manitoba. *Ten Thousand Years: Archaeology in Manitoba*, edited by W.M. Hlady, pp. 123-138. Manitoba Archaeological Society, Winnipeg.

Thorpe, J.
1999 Natural Vegetation. In *Atlas of Saskatchewan*, edited by K. Fung, B. Barry, and M. Wilson, pp.133-138. University of Saskatchewan, Saskatoon.

Tratebas, A.M.
1998 Reexamining the Plains Archaic McKean Culture. In *Explorations in American Archaeology: Essays in Honor of Wesley* R. *Hurt,* edited by M.G. Plew, pp. 259-309. University Press of America Inc., Lanham.

Twiss, P.C.
1992 Predicted World Distribution of C3 and C4 Grass Phytoliths. In *Phytolith Systematic: Emerging Issues*, edited by G. Rapp and S.C. Mulholland, pp. 113-128. Plenum Press, New York.

Twiss, P.C., E. Suess and R.M. Smith
1969 Morphological Classification of Grass Phytoliths. *Soil Science Society of America Proceedings* 33: 109-115.

van der Merwe, N.J.
1982 Carbon Isotopes, Photosynthesis, and Archaeology: Different Pathways of Photosynthesis cause Characteristic Changes in Carbon Isotope Ratios that make Possible the Study of Prehistoric Human Diets. *American Scientist* 70: 596-606.

Vance, R.E., A.B. Beaudoin, and B.H. Luckman
1995 The Paleoecological Record of 6ka B.P. Climate in the Canadian Prairie Provinces. *Geographie Physique et Quaternaire* 49: 81-98.

Vance, R.E. J.J. Clague and R.W. Mathewes
1993 Holocene Paleohydrology of a Hypersaline Lake in Southeastern Alberta. *Journal of Paleolimnology* 8: 103-120.

Vance, R.E., D. Emerson and T. Habgood
1983 A Mid-Holocene Record of Vegetative Change in Central Alberta. *Canadian Journal of Earth Sciences* 20: 364-376.

Vance, R.E., R.W. Mathewes, and J.J. Clague
1992 7000 Year Record of Lake-Level Change on the Northern Great Plains: A High-Resolution Proxy of Past Climate. *Geology* 20: 879-882.

Vickers, J.R.
1994 Cultures on the Northwestern Plains: From the Boreal Forest Edge to the Milk River. In *Plains Indians, A.D. 500 – 1500: The Archaeological Past of Historic Groups*, edited by Karl H. Schlesier, pp. 3-33. University of Oklahoma Press, Norman.

Vincent, L., X. Zhang, E. Mekis, R. Brown, W. Skinner, T. Agnew, and D. Sauchyn.
2004 Chapter 2: Past and Recent Trends in Canada's Climate. In *Climate Variability and Change in Canada: Past, Present and Future*, edited by E. B. Barrow, B. Maxwell and P. Gachon, pp. 5-10. ACSD Science Assessment Series No. 2, Meteorological Service of Canada, Environment Canada, Toronto, Ontario.

Walde, D.A., D. Meyer and W. Unfreed.
1995 The Late Prehistoric Period in the Northern Plains. *Revisita de Arquelogia Americana* 9: 7-66.

Walker, E.G.
1983 *Archaeological Resource Assessment: The Tipperary Creek Project.* Westek Consulting Limited, Saskatoon.

1992 *The Gowen Sites: Cultural Responses to Climatic Warming on the Northern Plains (7500-5000 B.P.).* Mercury Series 145. Archaeological Survey of Canada, Hull.

1999 Precontact Archaeology of Southern Saskatchewan. In *Atlas of Saskatchewan*, 2nd Edition, edited by K. Fung, p. 25-27. University of Saskatchewan, Saskatoon.

Wang, D. and D.W. Anderson
1998 Direct Measurement of Organic Carbon Content in Soils by the Leco CR-12 Carbon Analyser. *Communications on Soil Science and Plant Analysis* 29: 15-21.

Wang, Y., R. Amundson and S. Trumbore
1996 Radiocarbon Dating of Soil Organic Matter. *Quaternary Research* 45: 282-288.

Wanuskewin Heritage Park
2012a Our Story. Electronic document, http://wanuskewin.yastechserver.com/about-us/our-story/, accessed November 19, 2012.

2012b Archaeological Wonders. Electronic document, http://wanuskewin.yastechserver.com/seeking-knowledge/archaeological-research/, accessed November 19, 2012.

Waters, M.R.
1992 *Principles of Geoarchaeology: A North American Perspective.* The University of Arizona Press, Tucson.

Webster, S.M.
2004 A Re-Evaluation of the McKean Series on the Northern Plains. Unpublished Ph.D. dissertation, Department of Archaeology, University of Saskatchewan, Saskatoon.

Wedel, W.R.
1961 *Prehistoric Man on the Great Plains.* University of Oklahoma Press, Norman.

Wettlaufer, B.N.
1955 The Mortlach Site in the Besant Valley of Central Saskatchewan. *Anthropological Series No. 1,* Department of Natural Resources, Regina.

Whitaker, S.H. and E.A. Christiansen
1972 The Empress Group in Southern Saskatchewan. *Canadian Journal of Earth Sciences* 9: 353-360.

Wormington, H.M., and R.G. Forbis
1965 *An Introduction to the Archaeology of Alberta, Canada.* Proceedings No. 11, Denver Museum of Natural History, Denver.

Wright, J.V.
1995 *A History* of *the Native People* of *Canada. Volume I (10,000-1,000* B. C.). Mercury Series, Archaeological Survey of Canada Paper 152. Canadian Museum of Civilization, Hull.

Yansa, C.H.
1998 Holocene Paleovegetation and Paleohydrology of a Prairie Pothole in Southern Saskatchewan, Canada. *Journal of Paleolimnology* 19: 429-441.

2007 Lake Records of Northern Plains Paleoindian and Early Archaic Environments: The "Park Oasis" Hypothesis. *Plains Anthropologist* 52: 109-144.

Appendix A. Descriptive Core Logs

Table A.1 Descriptive core log of WNS-RT-03

Sample Name	Drive Number	Uncorrected Top Depth (cm)	Uncorrected Bottom Depth (cm)	Munsell Colour (damp)	Soil Horizon	Texture (by feel)	Structure	Consistence	Lower Boundary	Mottling	Effervescence	Inclusions
0 - 9 cm	1	0	9	10YR2/1 black	A	SiCL	structureless	v. fr.; sl. sticky	gradual	none	none	roots from modern veg.
9 - 20 cm	1	9	20	10YR3/2 very dark greyish brown	AB	CL	structureless	v. fr.; sl. sticky	gradual	none	none	none
20 - 41 cm U	1	20	30	10YR2/1 black	A	CL	structureless	v. fr.; sl. sticky	very gradual	none	none	none
20 - 41 cm L	1	30	41	10YR3.5/2 dark greyish brown	AB	L	structureless	v. fr.; sl. sticky	gradual	none	none	none
41 - 50 cm	1	41	50	10YR4/3 brown	B	SL	structureless	v. fr.; sl. sticky	gradual	none	none	none
50 - 59 cm	1	50	59	2.5Y4/2 dark greyish brown	C	SL	structureless	v. fr.; sl. sticky	clear	none	none	none
59 - 64 cm	1	59	64	10YR2/1 black	A	CL	structureless	fr.; sl. sticky	gradual	none	v. sl.	few roots
64 - 70 cm	1	64	70	10YR4/3 brown	B	SiCL	structureless	fr.; sl. sticky	gradual	none	sl.	gravelly, esp. top of layer
70 - 73 cm	1	70	73	10YR4/3 brown	A	CL	structureless	fr.; sl. sticky	clear	none	v. sl.	none
73 - 79 cm	1	73	79	2.5Y4/2 dark grayish brown	B	LS	structureless	fr.; sl. sticky	clear	none	none	none
79 - 84 cm	1	79	84	2.5Y3/1 very dark grey	A	SiCL	structureless	fr.; sticky	very clear	none	none	none
84 - 90 cm	1	84	90	10YR4/2 dark grayish brown	C	LS	structureless	v. fr.; sl. sticky	very clear	none	sl.	poorly sorted gravel
90 - 92 cm	1	90	92	2.5Y2.5/1 black	A	CL	structureless	fr.; sticky	clear	none	sl.	none
92 - 97 cm	1	92	97	2.5Y3/2 very dark greyish brown	B	SiC	structureless	fr.; sticky	end	none	sl.	none
DSS	1	97	107									

Table A.1 (continued). Descriptive core log of WNS-RT-03

Sample Name	Drive Number	Uncorrected Top Depth (cm)	Uncorrected Bottom Depth (cm)	Munsell Colour (damp)	Soil Horizon	Texture (by feel)	Structure	Consistence	Lower Boundary	Mottling	Effervescence	Inclusions
0 - 2 cm	2	107	109	2.5Y3/2 very dark greyish brown	B	SCL	structureless	fr.; sl. sticky	clear	none	none	none
2 - 5 cm	2	109	112	10YR2/1 black	A	SiCL	structureless	fr.; sticky	clear	none	none	none
5 - 7 cm	2	112	114	2.5Y3.5/2 very dark greyish brown	AB	SL	structureless	fr.; sl. sticky	gradual	none	none	some gravel
7 - 16 cm	2	114	123	2.5Y3/2 very dark greyish brown	AB?	CL	structureless	v. sticky	gradual	none	none	some organic matter
16 - 22 cm	2	123	129	2.5Y3/2 very dark greyish brown	A	SiCL	structureless	sticky	gradual	none	sl.	none
22 - 83 cm U	2	129	149	10YR4/2 dark graysih brown	B	S	structureless	v. fr.	-	none	v. sl.	small amount gravel throughout
22 - 83 cm M	2	149	169	2.5Y4/3 olive brown		S	structureless	v. fr.	-	none	v. sl.	small amount gravel throughout
22 - 83 cm L	2	169	190	2.5Y4/3 olive brown		S	structureless	v. fr.	end	none	v. sl.	small amount gravel throughout
DSS	2	190	200									
0 - 5 cm	3	200	205	2.5Y4/4 olive brown		SL	structureless	fr.	gradual	none	sl.	small carbonates present, few small pebbles
5 - 8 cm	3	205	208	2.5Y3/2 very dark greyish brown	A	SiCL	structureless	v. fr.	gradual	none	sl.	very few small pebbles
8 - 9 cm	3	208	209	2.5Y3/1 very dark brown	A	SiC	structureless	v. fr.	clear	none	v. sl.	
9 - 68 cm U	3	209	229	2.5Y4/3 olive brown	B?	SL	structureless	v. fr.	gradual	none	sl.	occasional pebbles, small amount of gravel
9 - 68 cm M	3	229	249	2.5Y4/3 olive brown		SL	structureless	v. fr.	gradual	none	sl.	none
9 - 68 cm L	3	249	268	2.5Y5/3 light olive brown		SL	structureless	v. fr.	end	none	sl.	more gritty than above
DSS	3	268	278									

Table A.1 (continued). Descriptive core log of WNS-RT-03.

Sample Name	Drive Number	Uncorrected Top Depth (cm)	Uncorrected Bottom Depth (cm)	Munsell Colour (damp)	Soil Horizon	Texture (by feel)	Structure	Consistence	Lower Boundary	Mottling	Effervescence	Inclusions
0 - 2 cm	4	278	280	2.5Y4/2 dark greyish brown	A?	SiCL	structureless	fr.	clear	none	sl.	none
2 - 3 cm	4	280	281	10YR3/2 very dark greyish brown	B	SiC	structureless	fr.	clear	none	sl.	none
3 - 81 cm U	4	281	307	2.5Y4/4 olive brown	B	S	structureless	v. fr.	-	none	none	some gravel throughout
3 - 81 cm M	4	307	333	2.5Y4/4 olive brown		S	structureless	v. fr.	-	none	none	
3 - 81 cm L	4	333	359	2.5Y4/4 olive brown		S	structureless	v. fr.	end	none	none	less gravel than above
DSS	4	359	369									
0 - 6 cm	5	369	375	2.5Y4/4 olive brown	A?	SL	structureless		clear	none	sl.	
6 - 8 cm	5	375	377	2.5Y3/2 very dark greyish brown	B	SiCL	structureless		clear	none	sl.	
8 - 16 cm	5	377	385	2.5Y4/2 dark greyish brown		SL	structureless		gradual	none	mod.	horizontal laminae
16 - 52 cm U	5	385	403	2.5Y4/3 olive brown		S	structureless		gradual	none	mod.	some larger gravels throughout
16 - 52 cm L	5	403	421	2.5Y4/3 olive brown		S	structureless		gradual	none	sl.	more coarse than sandy layer below
52 - 84 cm U	5	421	437	10YR4/6 dark yellowish brown		LS	structureless		gradual	reddish, orange particles	sl.	horizontal laminae
52 - 84 cm L	5	437	453	2.5Y4/4 olive brown		LS	structureless		end	fewer than above	sl.	horizontal laminae
DSS	5	453	463									
0 - 12 cm	6	463	475	2.5Y4/2 dark greyish brown		LS	structureless	v. fr.	clear	none	sl.	none
12 - 17 cm	6	475	480	2.5Y3/2 very dark greyish brown		SCL	structureless	v. fr.	clear	none	v. sl.	slightly mixed up with sandy layer below

Table A.1 (continued). Descriptive core log of WNS-RT-03.

Sample Name	Drive Number	Uncorrected Top Depth (cm)	Uncorrected Bottom Depth (cm)	Munsell Colour (damp)	Soil Horizon	Texture (by feel)	Structure	Consistence	Lower Boundary	Mottling	Effervescence	Inclusions
17 - 66 cm U	6	480	496	2.5Y4/3 olive brown		LS	structureless	v. fr.	clear	none	v. sl.	none
17 - 66 cm M	6	496	512	2.5Y4/3 olive brown		LS	structureless	v. fr.	clear	none	v. sl.	none
17 - 66 cm L	6	512	529	2.5Y4/3 olive brown		LS	structureless	v. fr.	clear	none	v. sl.	none
66 - 67 cm	6	529	530	7.5YR4/6 strong brown		LS	structureless	v. fr.	clear	none	none	reddish band above gravel
67 - 74 cm	6	530	537	-		S	structureless		clear	none	none	very gravelly
74 - 79 cm	6	537	542	10YR4/6 dark yellowish brown		SL	structureless		gradual	none	none	
79 - 87 cm	6	542	550	10YR3/6 dark yellowish brown		SL	structureless		end	none	none	
DSS	6	550	560									
0 - 10 cm	7	560	570	2.5Y3/3 dark olive brown		S	structureless		gradual	mixed darker patches	none	some larger gravels (~8-10mm)
10 - 28 cm	7	570	588	10YR4/6 dark yellowish brown		S	structureless		clear	none	sl.	lots of gravel, orange-reddish colour
28 - 34 cm	7	588	594	10YR5/4 yellowish brown		S	structureless		gradual	none	mod.	gravel up to ~20mm
34 - 53 cm U	7	594	600	2.5Y3/1 very dark grey		C	structureless			none	none	some gravel throughout
34 - 53 cm M	7	600	606	2.5Y3/1 very dark grey		C	structureless			none	none	
34 - 53 cm L	7	606	613	2.5Y3/1 very dark grey		C	structureless		end	none	none	

Table A.1 (continued). Descriptive core log of WNS-RT-03.

Sample Name	Drive Number	Uncorrected Top Depth (cm)	Uncorrected Bottom Depth (cm)	Munsell Colour (damp)	Soil Horizon	Texture (by feel)	Structure	Consistence	Lower Boundary	Mottling	Effervescence	Inclusions
17 - 66 cm U	6	480	496	2.5Y4/3 olive brown		LS	structureless	v. fr.	clear	none	v. sl.	none
17 - 66 cm M	6	496	512	2.5Y4/3 olive brown		LS	structureless	v. fr.	clear	none	v. sl.	none
17 - 66 cm L	6	512	529	2.5Y4/3 olive brown		LS	structureless	v. fr.	clear	none	v. sl.	none
66 - 67 cm	6	529	530	7.5YR4/6 strong brown		LS	structureless	v. fr.	clear	none	none	reddish band above gravel
67 - 74 cm	6	530	537	-		S	structureless		clear	none	none	very gravelly
74 - 79 cm	6	537	542	10YR4/6 dark yellowish brown		SL	structureless		gradual	none	none	
79 - 87 cm	6	542	550	10YR3/6 dark yellowish brown		SL	structureless		end	none	none	
DSS	6	550	560									
0 - 10 cm	7	560	570	2.5Y3/3 dark olive brown		S	structureless		gradual	mixed darker patches	none	some larger gravels (~8-10mm)
10 - 28 cm	7	570	588	10YR4/6 dark yellowish brown		S	structureless		clear	none	sl.	lots of gravel, orange-reddish colour
28 - 34 cm	7	588	594	10YR5/4 yellowish brown		S	structureless		gradual	none	mod.	gravel up to ~20mm
34 - 53 cm U	7	594	600	2.5Y3/1 very dark grey		C	structureless			none	none	some gravel throughout
34 - 53 cm M	7	600	606	2.5Y3/1 very dark grey		C	structureless			none	none	
34 - 53 cm L	7	606	613	2.5Y3/1 very dark grey		C	structureless		end	none	none	

Table A.2. Descriptive core log of WNS-RT-05.

Sample Name	Drive Number	Uncorrected Top Depth (cm)	Uncorrected Bottom Depth (cm)	Munsell Colour (damp)	Soil Horizon	Texture (by feel)	Structure	Lower Boundary	Mottling	Effervescence	Inclusions & Notes
0 - 33 cm U	1	0	17	10YR2/1 black	A	L	fine platy	gradual	none	none	roots from modern vegetation
0 - 33 cm L	1	17	33	10YR2/1 black	A	L	structureless	gradual	none	none	fine gravel
33 - 39 cm	1	33	39	10YR3/2 very dark greyish brown	C	SiCL	structureless	clear	none	none	larger pebbles (~20mm)
39 - 46 cm	1	39	46	2.5Y3/2 very dark greyish brown	C	SiCL	structureless	gradual	none	none	fewer gravels than above
46 - 58 cm	1	46	58	2.5Y3/2 very dark greyish brown	C	SL	structureless		none	none	darker bands throughout
58 - 62 cm	1	58	62	10YR2/1 black	A	CL	structureless	clear	none	none	none
62 - 66 cm	1	62	66	2.5Y3/2 very dark greyish brown	C	SiCL	structureless	gradual	none	none	none
66 - 75 cm	1	66	75	2.5Y3/2 very dark greyish brown	C	CL	structureless	clear	none	none	large cracked rock at lower boundary
75 - 88 cm	1	75	88	2.5Y4/2 dark greyish brown	C	SL	structureless	end	none	none	none
DSS	1	88	98	2.5Y4/2 dark greyish brown		LS	structureless	-	none	v. sl.	none
0 - 18 cm	2	98	116	2.5Y4/2 dark greyish brown	C	SL	structureless	clear	none	none	few gravel (~2-10mm)
18 - 20 cm	2	116	118	2.5Y3/2 very dark greyish brown	C	SiCL	structureless	clear	none	none	none
20 - 22 cm	2	118	120	10YR2/1 black	A	CL	structureless	clear	none	sl.	potential buried soil
22 - 25 cm	2	120	123	2.5Y3/2 very dark greyish brown	A	CL	structureless	gradual	none	sl.	none

Table A.2 (continued). Descriptive core log of WNS-RT-05.

Sample Name	Drive Number	Uncorrected Top Depth (cm)	Uncorrected Bottom Depth (cm)	Munsell Colour (damp)	Soil Horizon	Texture (by feel)	Structure	Lower Boundary	Mottling	Effervescence	Inclusions & Notes
25 - 29 cm	2	123	127	2.5Y4/2 dark greyish brown	AB	SL	structureless	gradual	none	v. sl.	none
29 - 33 cm	2	127	131	10YR4/2 dark greyish brown	A	SiCL	structureless	clear	none	none	none
33 - 40 cm	2	131	138	2.5Y4/2 dark greyish brown	A	SL	structureless	gradual	none	sl.	some gravel (~2-7mm)
40 - 58 cm	2	138	156	2.5Y4/2 dark greyish brown	C	SL	structureless	gradual	none	sl.	none
58 - 84 cm U	2	156	169	2.5Y5/4 light olive brown		S	structureless	-	none	sl.	none
58 - 84 cm L	2	169	182	2.5Y5/4 light olive brown		S	structureless	end	none	mod.	carbonates present (str. effervescent)
DSS	2	182	192	2.5Y4/3 olive brown		S	structureless	-	none	v. sl.	none
0 - 10 cm	3	192	202	2.5Y4/4 olive brown	C	SL	structureless	unclear	none	mod.	carbonates present (str. effervescent)
10 - 22 cm	3	202	214	2.5Y4/4 olive brown	C	SL	blocky	unclear	none	mod.	carbonates present (str. effervescent)
22 - 31 cm	3	214	223	2.5Y4/3 olive brown	C	LS	structureless	unclear	none	sl.	no carbonates present
31 - 34 cm	3	223	226	2.5Y4/4 olive brown	C	SL	structureless	gradual	none	str.	carbonates present (str. effervescent)
34 - 83 cm U	3	226	242	2.5Y4/4 olive brown	C	SL	structureless	-	none	str.	some gravel throughout (<10mm)
34 - 83 cm M	3	242	258	2.5Y4/4 olive brown		SL	structureless	-	none	str.	carbonates present (str. effervescent)
34 - 83 cm L	3	258	275	2.5Y4/4 olive brown	C	SL	structureless	end	none	str.	carbonates present (str. effervescent)
DSS	3	275	285	2.5Y4/4 olive brown		SL	structureless	-	none	mod.	none
0 - 4 cm	4	285	289	2.5Y4/3 olive brown		SL	structureless	clear	none	str.	none
4 - 5 cm	4	289	290	10YR2/1 black	A	CL	structureless	clear	none	v. sl.	possible buried A horizon

Table A.2 (continued). Descriptive core log of WNS-RT-05.

Sample Name	Drive Number	Uncorrected Top Depth (cm)	Uncorrected Bottom Depth (cm)	Munsell Colour (damp)	Soil Horizon	Texture (by feel)	Structure	Lower Boundary	Mottling	Effervescence	Inclusions & Notes
5 - 18 cm	4	290	303	2.5Y4/2 dark greyish brown	C	SL	structureless	gradual	none	-	carbonates present (str. effervescent), increasing gravel towards bottom (<12mm)
18 - 29 cm	4	303	314	2.5Y5/3 olive		SL	structureless	gradual	none	str.	finer sand than below - fining upward sequence?
29 - 43 cm	4	314	328	2.5Y4/3 olive brown		S	structureless	gradual	none	mod.	small amount of gravel (<10mm)
43 - 84 cm U	4	328	348	2.5Y4/3 olive brown		S	structureless	-	none	sl.	none
43 - 84 cm L	4	348	369	2.5Y4/3 olive brown		S	structureless	end	none	sl.	very small amount of gravel (~2-12mm)
DSS	4	369	379	10YR5/6 yellowish brown		S	structureless	Sl. Eff	none	sl.	
17 - 53 cm U	5	379	391	10YR4/4 dark yellowish brown		S	structureless	clear	some darker spots	mod.	darker bands throughout (horizontal laminae)
17 - 53 cm M	5	391	403	10YR4/4 dark yellowish brown		S	structureless	clear	none	mod.	darker bands throughout (horizontal laminae)
17 - 53 cm L	5	403	415	10YR4/4 dark yellowish brown		S	structureless	gradual	none	mod.	darker bands throughout (horizontal laminae)
53 - 65 cm	5	415	427	10YR4/4 dark yellowish brown		S	structureless	gradual	orange/red spots	sl.	some small gravel (<7mm)
65 - 69 cm	5	427	431	10YR4/4 dark yellowish brown	C	S	structureless	gradual	none	sl.	more coarse than above, reddish in colour
69 - 75 cm	5	431	437	2.5Y5/4 light olive brown		S	structureless	gradual	none	v. sl.	finer sand than above, very little gravel
75 - 80 cm	5	437	442	10YR4/4 dark yellowish brown	C	S	structureless	gradual	none	sl.	no gravel
80 - 102 cm U	5	442	453	2.5Y5/3 olive		S	structureless	gradual	none	v. sl.	
80 - 102 cm L	5	453	464	2.5Y5/3 olive		S	structureless	gradual	none		one larger pebble (14mm)

Table A.2 (continued). Descriptive core log of WNS-RT-05.

Sample Name	Drive Number	Uncorrected Top Depth (cm)	Uncorrected Bottom Depth (cm)	Munsell Colour (damp)	Soil Horizon	Texture (by feel)	Structure	Lower Boundary	Mottling	Effervescence	Inclusions & Notes
DSS	5	464	474	10YR4/4 dark yellowish brown		S	structureless	-	-	none	none
0 - 12 cm	6	474	486	10YR3/6 dark yellowish brown		LS	structureless	clear	some reddish spots	none	none
12 - 15 cm	6	486	489	2.5Y2.5/1 black			structureless	clear	none	none	black portion of the sample very small, didn't extend back into core
15 - 29 cm	6	489	503	2.5Y3/3 dark olive brown		S	structureless	clear	none	none	lots of small gravel throughout (<5mm)
29 - 40 cm	6	503	514	7.5YR4/6 strong brown		S	structureless	end	none	none	lots of small gravel throughout (<5mm)
DSS	6	514	524	7.5YR4/6 strong brown		S	structureless	-	none	sl.	none
0 - 16 cm	7	524	540	7.5YR4/6 strong brown		S	structureless	clear	none		large pebble, full circumference of coring tube
16 - 32 cm	7	540	556	2.5Y3.5/1 dark olive brown		C	structureless	gradual	none	v. sl.	some small gravel
32 - 48 cm	7	556	572	2.5Y3.5/1 dark olive brown		C	structureless	gradual	none	v. sl.	some small gravel (<5mm)
48 - 64 cm	7	572	588	2.5Y3.5/1 dark olive brown		C	structureless	gradual	none	sl.	large pebble (28mm)
64 - 79 cm	7	588	603	2.5Y3.5/1 dark olive brown		C	structureless	gradual	none	sl.	some small gravel (<5mm)
79 - 95 cm	7	603	619	2.5Y3.5/1 dark olive brown		C	structureless	gradual	none	sl.	some small gravel (<5mm)
95 - 114 cm	7	619	638	2.5Y3.5/1 dark olive brown		C	structureless	gradual	none	v. sl.	some small gravel (<5mm)
DSS	7	638	648	2.5Y3/1 very dark grey		C	-	V. Sl Eff	-	-	none

Appendix B. Particle Size Analysis Results

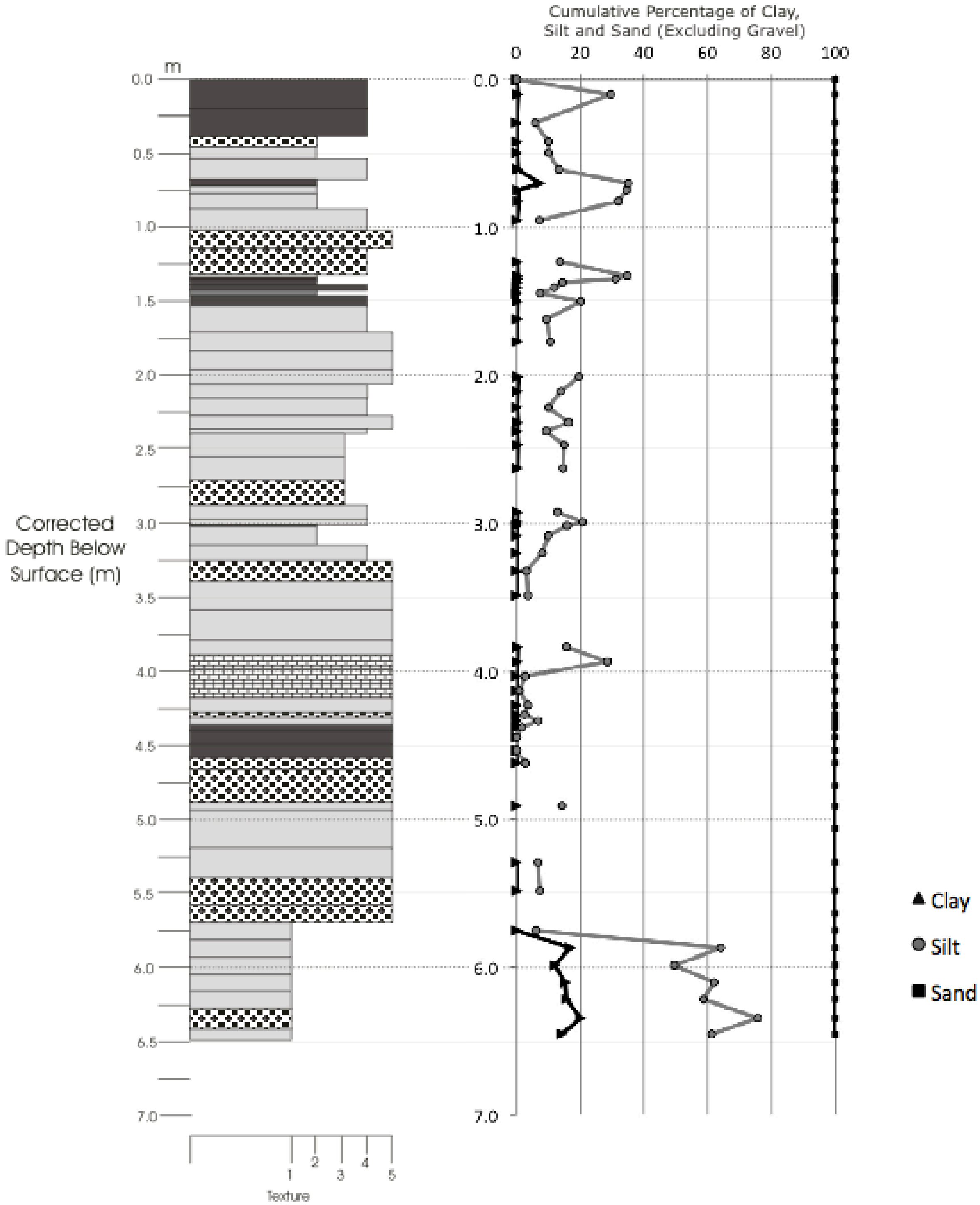


Figure B.1. Particle size analysis results from WNS-RT-05.

Appendix C. Radiocarbon Dates

CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

(Variables: C13/C12=-24.3:lab. mult=1)

Laboratory number: **Beta-343501**

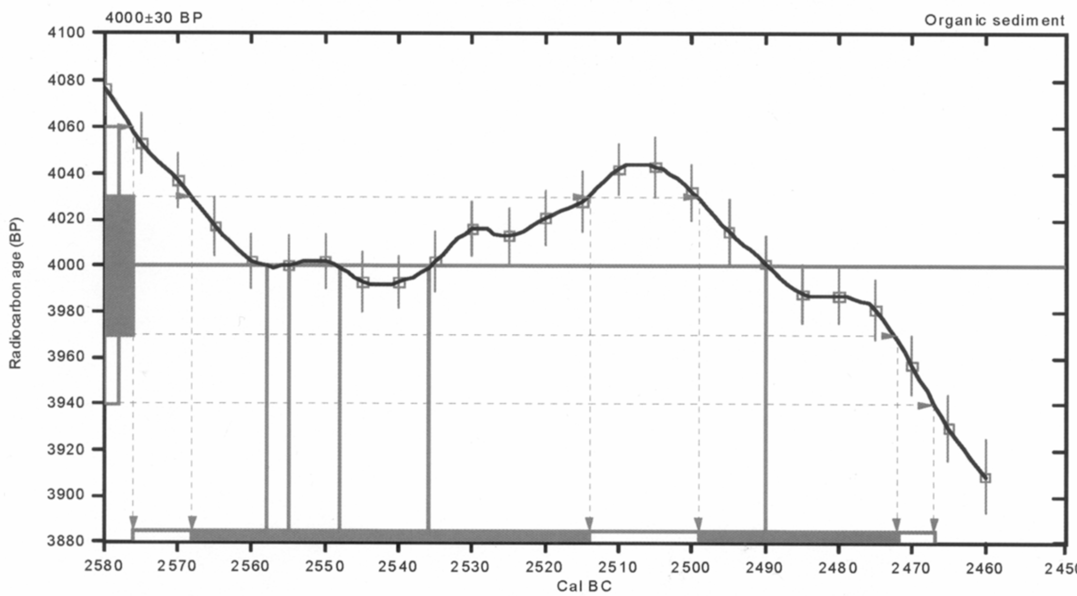
Conventional radiocarbon age: **4000±30 BP**

2 Sigma calibrated result: (95% probability) **Cal BC 2580 to 2470 (Cal BP 4530 to 4420)**

Intercept data

Intercepts of radiocarbon age with calibration curve: Cal BC 2560 (Cal BP 4510) and
Cal BC 2560 (Cal BP 4500) and
Cal BC 2550 (Cal BP 4500) and
Cal BC 2540 (Cal BP 4490) and
Cal BC 2490 (Cal BP 4440)

1 Sigma calibrated results: (68% probability) Cal BC 2570 to 2510 (Cal BP 4520 to 4460) and
Cal BC 2500 to 2470 (Cal BP 4450 to 4420)



References:

Database used

INTCAL09

References to INTCAL09 database

Heaton,et.al.,2009, Radiocarbon 51(4):1151-1164, Reimer,et.al, 2009, Radiocarbon 51(4):1111-1150, Stuiver,et.al,1993, Radiocarbon 35(1):1-244, Oeschger,et.al.,1975,Tellus 27:168-192

Mathematics used for calibration scenario

A Simplified Approach to Calibrating C14 Dates

Talma, A. S., Vogel, J. C., 1993, Radiocarbon 35(2):317-322

Beta Analytic Radiocarbon Dating Laboratory

4985 S.W. 74th Court, Miami, Florida 33155 • Tel: (305)667-5167 • Fax: (305)663-0964 • E-Mail: beta@radiocarbon.com

Figure C.1. Standard AMS radiocarbon date calibration of WNS-RT-05-02 20-22 cm.

CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

(Variables: C13/C12=-23:lab. mult=1)

Laboratory number: **Beta-343502**

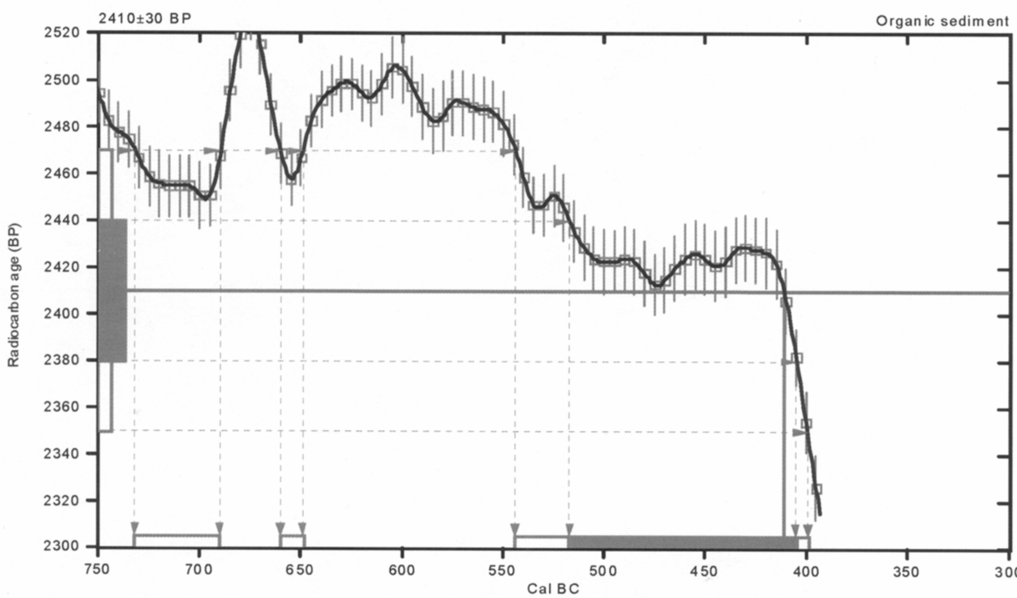
Conventional radiocarbon age: **2410±30 BP**

2 Sigma calibrated results: (95% probability) **Cal BC 730 to 690 (Cal BP 2680 to 2640) and**
Cal BC 660 to 650 (Cal BP 2610 to 2600) and
Cal BC 540 to 400 (Cal BP 2490 to 2350)

Intercept data

Intercept of radiocarbon age with calibration curve: Cal BC 410 (Cal BP 2360)

1 Sigma calibrated result: (68% probability) Cal BC 520 to 400 (Cal BP 2470 to 2360)



References:

Database used
INTCAL09
References to INTCAL09 database
Heaton,et.al.,2009, Radiocarbon 51(4):1151-1164, Reimer,et.al, 2009, Radiocarbon 51(4):1111-1150, Stuiver,et.al,1993, Radiocarbon 35(1):1-244, Oeschger,et.al.,1975,Tellus 27:168-192
Mathematics used for calibration scenario
A Simplified Approach to Calibrating C14 Dates
Talma, A. S., Vogel, J. C., 1993, Radiocarbon 35(2):317-322

Beta Analytic Radiocarbon Dating Laboratory

4985 S.W. 74th Court, Miami, Florida 33155 • Tel: (305)667-5167 • Fax: (305)663-0964 • E-Mail: beta@radiocarbon.com

Figure C.2. Standard AMS radiocarbon date calibration of WNS-RT-05-05 12-17 cm.

Appendix D. Tabulated Phytolith Data from WNS-RT-05

Table D.1. Raw counts of short-cell phytolith morphotypes in sediment samples from WNS-RT-05.

Sample Number	Drive Number	Uncorrected Top Depth Below Surface (m)	Uncorrected Bottom Depth Below Surface (m)	Corrected Top Depth Below Surface (m)	Corrected Bottom Depth Below Surface (m)	Corrected Midpoint Below Surface (m)	Munsell Colour (damp)	Soil Horizon	Phytolith Morphotype A Raw Count	Phytolith Morphotype B Raw Count	Phytolith Morphotype C Raw Count	Phytolith Morphotype D Raw Count	Phytolith Morphotype E Raw Count	Phytolith Morphotype F Raw Count	Phytolith Morphotype G Raw Count	Phytolith Morphotype H Raw Count	Total Short Cell Raw Count
0-33cm U	1	0.00	0.17	0.00	0.20	0.10	10YR2/1 black	A	65	35	0	20	16	47	0	0	183
0-33cm L	1	0.17	0.33	0.20	0.38	0.29	10YR2/1 black	A	62	15	37	22	14	42	0	0	192
33-39cm	1	0.33	0.39	0.38	0.45	0.42	10YR3/2 very dark greyish brown	C	2	0	1	0	0	2	0	0	5
39-46cm	1	0.39	0.46	0.45	0.54	0.50	2.5Y3/2 very dark greyish brown	C	0	0	1	2	0	2	0	0	5
46-58cm	1	0.46	0.58	0.54	0.68	0.61	2.5Y3/2 very dark greyish brown	C	1	0	1	0	0	1	0	0	3
58-62cm	1	0.58	0.62	0.68	0.72	0.70	10YR2/1 black	A	1	0	4	0	0	0	0	0	5
62-66cm	1	0.62	0.66	0.72	0.77	0.75	2.5Y3/2 very dark greyish brown	C	1	0	2	1	0	0	0	0	4
66-75cm	1	0.66	0.75	0.77	0.87	0.82	2.5Y3/2 very dark greyish brown	C	2	1	0	0	0	0	0	0	3
75-88cm	1	0.75	0.88	0.87	1.03	0.95	2.5Y4/2 dark greyish brown	C	0	0	1	0	0	0	0	0	1
0-18cm	2	0.98	1.16	1.14	1.32	1.23	2.5Y4/2 dark greyish brown	C	0	0	0	0	0	0	0	0	0
18-20cm	2	1.16	1.18	1.32	1.34	1.33	2.5Y3/2 very dark greyish brown	C	0	1	0	0	0	1	0	0	2
20-22cm	2	1.18	1.20	1.34	1.36	1.35	10YR2/1 black	A	8	0	26	6	5	36	0	0	81
22-25cm	2	1.20	1.23	1.36	1.39	1.37	2.5Y3/2 very dark greyish brown	A	3	0	6	6	0	0	0	0	15

Table D.1 (continued). Raw counts of short-cell phytolith morphotypes in sediment samples from WNS-RT-05.

Sample Number	Drive Number	Uncorrected Top Depth Below Surface (m)	Uncorrected Bottom Depth Below Surface (m)	Corrected Top Depth Below Surface (m)	Corrected Bottom Depth Below Surface (m)	Corrected Midpoint Below Surface (m)	Munsell Colour (damp)	Soil Horizon	Phytolith Morphotype A Raw Count	Phytolith Morphotype B Raw Count	Phytolith Morphotype C Raw Count	Phytolith Morphotype D Raw Count	Phytolith Morphotype E Raw Count	Phytolith Morphotype F Raw Count	Phytolith Morphotype G Raw Count	Phytolith Morphotype H Raw Count	Total Short Cell Raw Count
25-29cm	2	1.23	1.27	1.39	1.42	1.41	2.5Y4/2 dark greyish brown	AB	2	3	0	4	0	1	2	0	12
29-33cm	2	1.27	1.31	1.42	1.46	1.44	10YR4/2 dark greyish brown	A	7	0	8	1	3	5	0	0	24
33-40cm	2	1.31	1.38	1.46	1.53	1.50	2.5Y4/2 dark greyish brown	A	7	9	0	3	2	14	0	0	35
40-58cm	2	1.38	1.56	1.53	1.71	1.62	2.5Y4/2 dark greyish brown	C	3	0	0	1	0	1	0	0	5
0-10cm	3	1.92	2.02	2.06	2.16	2.11	2.5Y4/4 olive brown	C	1	0	1	0	0	0	0	0	2
10-22cm	3	2.02	2.14	2.16	2.27	2.21	2.5Y4/4 olive brown	C	0	0	0	0	0	0	0	0	0
22-31cm	3	2.14	2.23	2.27	2.36	2.32	2.5Y4/3 olive brown	C	0	0	0	0	0	0	0	0	0
31-34cm	3	2.23	2.26	2.36	2.39	2.38	2.5Y4/4 olive brown	C	0	0	0	0	0	0	0	0	0
34-83cm U	3	2.26	2.42	2.39	2.55	2.47	2.5Y4/4 olive brown	C	0	0	0	0	0	0	0	0	0
34-83cm L	3	2.58	2.75	2.71	2.87	2.79	2.5Y4/4 olive brown	C	0	0	0	0	0	0	0	0	0
4-5cm	4	2.89	2.90	3.01	3.02	3.01	10YR2/1 black	A	38	6	76	20	0	56	0	0	196
5-18cm	4	2.90	3.03	3.02	3.15	3.08	2.5Y4/2 dark greyish brown	C	0	0	0	0	0	0	0	0	0
65-69cm	5	4.44	4.48	4.42	4.45	4.43	10YR4/4 dark yellowish brown	C	0	0	0	0	0	0	0	0	0
75-80cm	5	4.54	4.59	4.50	4.54	4.52	10YR4/4 dark yellowish brown	C	0	0	0	0	0	0	0	0	0

Table D.2. Percentage of short-cell phytolith morphotypes in sediment samples from WNS-RT-05.

Sample Number	Drive Number	Uncorrected Top Depth Below Surface (m)	Uncorrected Bottom Depth Below Surface (m)	Corrected Top Depth Below Surface (m)	Corrected Bottom Depth Below Surface (m)	Corrected Midpoint Below Surface (m)	Munsell Colour (damp)	Soil Horizon	Phytolith Morphotype A %	Phytolith Morphotype B %	Phytolith Morphotype C %	Phytolith Morphotype D %	Phytolith Morphotype E %	Phytolith Morphotype F %	Phytolith Morphotype G %	Phytolith Morphotype H %	Total Short Cell %
0-33cm U	1	0.00	0.17	0.00	0.20	0.10	10YR2/1 black	A	35.52	19.13	0.00	10.93	8.74	25.68	0.00	0.00	100.00
0-33cm L	1	0.17	0.33	0.20	0.38	0.29	10YR2/1 black	A	32.29	7.81	19.27	11.46	7.29	21.88	0.00	0.00	100.00
33-39cm	1	0.33	0.39	0.38	0.45	0.42	10YR3/2 very dark greyish brown	C	40.00	0.00	20.00	0.00	0.00	40.00	0.00	0.00	100.00
39-46cm	1	0.39	0.46	0.45	0.54	0.50	2.5Y3/2 very dark greyish brown	C	0.00	0.00	20.00	40.00	0.00	40.00	0.00	0.00	100.00
46-58cm	1	0.46	0.58	0.54	0.68	0.61	2.5Y3/2 very dark greyish brown	C	33.33	0.00	33.33	0.00	0.00	33.33	0.00	0.00	100.00
58-62cm	1	0.58	0.62	0.68	0.72	0.70	10YR2/1 black	A	20.00	0.00	80.00	0.00	0.00	0.00	0.00	0.00	100.00
62-66cm	1	0.62	0.66	0.72	0.77	0.75	2.5Y3/2 very dark greyish brown	C	25.00	0.00	50.00	25.00	0.00	0.00	0.00	0.00	100.00
66-75cm	1	0.66	0.75	0.77	0.87	0.82	2.5Y3/2 very dark greyish brown	C	66.67	33.33	0.00	0.00	0.00	0.00	0.00	0.00	100.00
75-88cm	1	0.75	0.88	0.87	1.03	0.95	2.5Y4/2 dark greyish brown	C	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	100.00
0-18cm	2	0.98	1.16	1.14	1.32	1.23	2.5Y4/2 dark greyish brown	C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18-20cm	2	1.16	1.18	1.32	1.34	1.33	2.5Y3/2 very dark greyish brown	C	0.00	50.00	0.00	0.00	0.00	50.00	0.00	0.00	100.00
20-22cm	2	1.18	1.20	1.34	1.36	1.35	10YR2/1 black	A	9.88	0.00	32.10	7.41	6.17	44.44	0.00	0.00	100.00
22-25cm	2	1.20	1.23	1.36	1.39	1.37	2.5Y3/2 very dark greyish brown	A	20.00	0.00	40.00	40.00	0.00	0.00	0.00	0.00	100.00

Table D.2 (continued). Percentage of short-cell phytolith morphotypes in sediment samples from WNS-RT-05.

Sample Number	Drive Number	Uncorrected Top Depth Below Surface (m)	Uncorrected Bottom Depth Below Surface (m)	Corrected Top Depth Below Surface (m)	Corrected Bottom Depth Below Surface (m)	Corrected Midpoint Below Surface (m)	Munsell Colour (damp)	Soil Horizon	Phytolith Morphotype A %	Phytolith Morphotype B %	Phytolith Morphotype C %	Phytolith Morphotype D %	Phytolith Morphotype E %	Phytolith Morphotype F %	Phytolith Morphotype G %	Phytolith Morphotype H %	Total Short Cell %
25-29cm	2	1.23	1.27	1.39	1.42	1.41	2.5Y4/2 dark greyish brown	AB	16.67	25.00	0.00	33.33	0.00	8.33	16.67	0.00	100.00
29-33cm	2	1.27	1.31	1.42	1.46	1.44	10YR4/2 dark greyish brown	A	29.17	0.00	33.33	4.17	12.50	20.83	0.00	0.00	100.00
33-40cm	2	1.31	1.38	1.46	1.53	1.50	2.5Y4/2 dark greyish brown	A	20.00	25.71	0.00	8.57	5.71	40.00	0.00	0.00	100.00
40-58cm	2	1.38	1.56	1.53	1.71	1.62	2.5Y4/2 dark greyish brown	C	60.00	0.00	0.00	20.00	0.00	20.00	0.00	0.00	100.00
0-10cm	3	1.92	2.02	2.06	2.16	2.11	2.5Y4/4 olive brown	C	50.00	0.00	50.00	0.00	0.00	0.00	0.00	0.00	100.00
10-22cm	3	2.02	2.14	2.16	2.27	2.21	2.5Y4/4 olive brown	C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22-31cm	3	2.14	2.23	2.27	2.36	2.32	2.5Y4/3 olive brown	C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
31-34cm	3	2.23	2.26	2.36	2.39	2.38	2.5Y4/4 olive brown	C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
34-83cm U	3	2.26	2.42	2.39	2.55	2.47	2.5Y4/4 olive brown	C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
34-83cm L	3	2.58	2.75	2.71	2.87	2.79	2.5Y4/4 olive brown	C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4-5cm	4	2.89	2.90	3.01	3.02	3.01	10YR2/1 black	A	19.39	3.06	38.78	10.20	0.00	28.57	0.00	0.00	100.00
5-18cm	4	2.90	3.03	3.02	3.15	3.08	2.5Y4/2 dark greyish brown	C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
65-69cm	5	4.44	4.48	4.42	4.45	4.43	10YR4/4 dark yellowish brown	C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
75-80cm	5	4.54	4.59	4.50	4.54	4.52	10YR4/4 dark yellowish brown	C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table D.3. Corrected counts of short-cell phytolith morphotypes in sediment samples from core WNS-RT-05.

Sample Number	Drive Number	Uncorrected Top Depth Below Surface (m)	Uncorrected Bottom Depth Below Surface (m)	Corrected Top Depth Below Surface (m)	Corrected Bottom Depth Below Surface (m)	Corrected Midpoint Below Surface (m)	Munsell Colour (damp)	Soil Horizon	Phytolith Morphotype A Corrected Count	Phytolith Morphotype B Corrected Count	Phytolith Morphotype C Corrected Count	Phytolith Morphotype D Corrected Count	Phytolith Morphotype E Corrected Count	Phytolith Morphotype F Corrected Count	Phytolith Morphotype G Corrected Count	Phytolith Morphotype H Corrected Count	Total Short Cell Corrected Count
0-33cm U	1	0.00	0.17	0.00	0.20	0.10	10YR2/1 black	A	1207895	650405	0	371660	297328	873401	0	0	3400689
0-33cm L	1	0.17	0.33	0.20	0.38	0.29	10YR2/1 black	A	576073	139373	343786	204413	130081	390243	0	0	1783968
33-39cm	1	0.33	0.39	0.38	0.45	0.42	10YR3/2 very dark greyish brown	C	906	0	453	0	0	906	0	0	2266
39-46cm	1	0.39	0.46	0.45	0.54	0.50	2.5Y3/2 very dark greyish brown	C	0	0	1093	2186	0	2186	0	0	5466
46-58cm	1	0.46	0.58	0.54	0.68	0.61	2.5Y3/2 very dark greyish brown	C	387	0	387	0	0	387	0	0	1161
58-62cm	1	0.58	0.62	0.68	0.72	0.70	10YR2/1 black	A	9292	0	37166	0	0	0	0	0	46458
62-66cm	1	0.62	0.66	0.72	0.77	0.75	2.5Y3/2 very dark greyish brown	C	845	0	1689	845	0	0	0	0	3379
66-75cm	1	0.66	0.75	0.77	0.87	0.82	2.5Y3/2 very dark greyish brown	C	1956	978	0	0	0	0	0	0	2934
75-88cm	1	0.75	0.88	0.87	1.03	0.95	2.5Y4/2 dark greyish brown	C	0	0	326	0	0	0	0	0	326
0-18cm	2	0.98	1.16	1.14	1.32	1.23	2.5Y4/2 dark greyish brown	C	0	0	0	0	0	0	0	0	0
18-20cm	2	1.16	1.18	1.32	1.34	1.33	2.5Y3/2 very dark greyish brown	C	0	227	0	0	0	227	0	0	453
20-22cm	2	1.18	1.20	1.34	1.36	1.35	10YR2/1 black	A	718	0	2334	539	449	3232	0	0	7272
22-25cm	2	1.20	1.23	1.36	1.39	1.37	2.5Y3/2 very dark greyish brown	A	1798	0	3597	3597	0	0	0	0	8992

Table D.3 (continued). Corrected counts of short-cell phytolith morphotypes in sediment samples from WNS-RT-05.

Sample Number	Drive Number	Uncorrected Top Depth Below Surface (m)	Uncorrected Bottom Depth Below Surface (m)	Corrected Top Depth Below Surface (m)	Corrected Bottom Depth Below Surface (m)	Corrected Midpoint Below Surface (m)	Munsell Colour (damp)	Soil Horizon	Phytolith Morphotype A Corrected Count	Phytolith Morphotype B Corrected Count	Phytolith Morphotype C Corrected Count	Phytolith Morphotype D Corrected Count	Phytolith Morphotype E Corrected Count	Phytolith Morphotype F Corrected Count	Phytolith Morphotype G Corrected Count	Phytolith Morphotype H Corrected Count	Total Short Cell Corrected Count
29-33cm	2	1.27	1.31	1.42	1.46	1.44	10YR4/2 dark greyish brown	A	518	0	592	74	222	370	0	0	1777
33-40cm	2	1.31	1.38	1.46	1.53	1.50	2.5Y4/2 dark greyish brown	A	1429	1906	1906	1906	0	4288	0	0	11436
33-40cm	2	1.31	1.38	1.46	1.53	1.50	2.5Y4/2 dark greyish brown	A	3335	4288	0	1429	953	6671	0	0	16677
40-58cm	2	1.38	1.56	1.53	1.71	1.62	2.5Y4/2 dark greyish brown	C	2323	0	0	774	0	774	0	0	3871
0-10cm	3	1.92	2.02	2.06	2.16	2.11	2.5Y4/4 olive brown	C	715	0	715	0	0	0	0	0	1429
10-22cm	3	2.02	2.14	2.16	2.27	2.21	2.5Y4/4 olive brown	C	0	0	0	0	0	0	0	0	0
22-31cm	3	2.14	2.23	2.27	2.36	2.32	2.5Y4/3 olive brown	C	0	0	0	0	0	0	0	0	0
31-34cm	3	2.23	2.26	2.36	2.39	2.38	2.5Y4/4 olive brown	C	0	0	0	0	0	0	0	0	0
34-83cm U	3	2.26	2.42	2.39	2.55	2.47	2.5Y4/4 olive brown	C	0	0	0	0	0	0	0	0	0
34-83cm L	3	2.58	2.75	2.71	2.87	2.79	2.5Y4/4 olive brown	C	0	0	0	0	0	0	0	0	0
4-5cm	4	2.89	2.90	3.01	3.02	3.01	10YR2/1 black	A	4469	706	8939	2352	0	6586	0	0	23052
5-18cm	4	2.90	3.03	3.02	3.15	3.08	2.5Y4/2 dark greyish brown	C	0	0	0	0	0	0	0	0	0
65-69cm	5	4.44	4.48	4.42	4.45	4.43	10YR4/4 dark yellowish brown	C	0	0	0	0	0	0	0	0	0
75-80cm	5	4.54	4.59	4.50	4.54	4.52	10YR4/4 dark yellowish brown	C	0	0	0	0	0	0	0	0	0